1.773
U.S. W4
W~

W. B. No. 659

U. S. DEPARTMENT OF AGRICULTURE

WEATHER BUREAU

CHARLES F. MARVIN, Chief

MONTHLY WEATHER REVIEW

VOLUME 46, No. 7

JULY, 1918

GENERAL LIBRARY
NOV 5 1918
UNIV. OF MICH.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

JULY, 1918.

CONTENTS.

	Page.
INTRODUCTION	307
SECTION I.—AEROLOGY:	
Solar and sky radiation measurements during July, 1918. H. H. Kimball	308
Absorption and radiation of the solar atmosphere. S. Hirayama. (Abstract)	309
Internal temperatures of the sun. A. Véronnet. (Abstract)	309
Halo phenomena observed during July, 1918. W. R. Gregg	309
SECTION II.—GENERAL METEOROLOGY:	
Report on modes of air motion and the equations of the general circulation of the earth's atmosphere. G. P. Paine. (6 figs.)	311
Influence of forests upon the melting of snow in the Cascade Range. A. A. Griffin. (3 figs.)	324
Snowfall on Mount Rainier, Wash. L. C. Fisher. (5 figs.).	
On severe winters. G. Hellmann. (Abstract)	327
SECTION III.—FORECASTS:	
Forecasts and warnings for July, 1918. H. C. Frankenfield. (Charts II and III)	331
SECTION IV.—RIVERS AND FLOODS:	
Rivers and floods, July, 1918. A. J. Henry. (Chart I)	332
Great Lakes levels during July, 1918	332
SECTION V.—SEISMOLOGY:	
Seismological reports for July, 1918. W. J. Humphreys	333
Seismological dispatches for July, 1918	339
SECTION VI.—BIBLIOGRAPHY:	
Recent additions to the Weather Bureau Library. C. F. Talman	340
Recent papers bearing on meteorology and seismology. C. F. Talman	340
SECTION VII.—WEATHER AND DATA FOR THE MONTH:	
Weather of July, 1918. P. C. Day	342
Weather conditions over the North Atlantic during July, 1917. (Chart IX)	343
Condensed climatological summary	345
Description of Tables and Charts	345
Tables—	
I. Climatological data for United States Weather Bureau stations	346
II. Accumulated amounts of precipitation	349
III. Data furnished by the Canadian Meteorological Service	351
Charts—	Chart.
I. Hydrographs, July, 1918	56
II. Tracks of centers of HIGHS	57
III. Tracks of centers of LOWS	58
IV. Departures of mean temperatures	59
V. Total precipitation for the month	60
VI. Percentage of clear sky	61
VII. Sea-level isobars and isotherms, and prevailing winds.	62
VIII. Total snowfall for the month	(Not charted.)
IX. Marine meteorological data for July, 1917	63

NOTICE TO CONTRIBUTORS.

Contributions intended for publication in any given issue of the MONTHLY WEATHER REVIEW (e. g., January) should be in the hands of the editor before the end of the next following month (e. g., February), if no illustrations are required. When the paper is illustrated, the manuscript and the copy for illustrations must be submitted much earlier, in order to permit copy being prepared for the engraver by the end of the month.

REPRINTS are made up without covers in the original size and pagination of the REVIEW. They will not be furnished unless specifically REQUESTED WHEN THE MANUSCRIPT IS SUBMITTED.

MONTHLY WEATHER REVIEW

HERBERT H. KIMBALL, Acting Editor.

VOL. 46, No. 7.
W. B. No. 659.

JULY, 1918.

CLOSED SEPTEMBER 3, 1918
ISSUED OCTOBER 31, 1918

INTRODUCTION.

As explained in this introduction during 1914, the MONTHLY WEATHER REVIEW now takes the place of the Bulletin of the Mount Weather Observatory and of the voluminous publication of the climatological service of the Weather Bureau. The MONTHLY WEATHER REVIEW contains contributions from the research staff of the Weather Bureau and also special contributions of a general character in any branch of meteorology and climatology.

SUPPLEMENTS to the MONTHLY WEATHER REVIEW are published from time to time.

The climatological service of the Weather Bureau is maintained in all its essential features, but its publications, so far as they relate to purely local conditions, are incorporated in the monthly reports "Climatological Data" for the respective States, Territories, and colonies. These are listed on page 3 of the cover.

Since August, 1915, the material for the MONTHLY WEATHER REVIEW has been prepared and classified in accordance with the following sections:

SECTION 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

SECTION 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

SECTION 3.—*Forecasts and general conditions of the atmosphere.*

SECTION 4.—*Rivers and floods.*

SECTION 5.—*Seismology.*—Results of observations by Weather Bureau observers and others as reported to the Washington office.

SECTION 6.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

SECTION 7.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto; Meteorological Summary and chart No. 9 of the North Atlantic Ocean for this month in 1917. Owing to the fact that ocean meteorological data are frequently not available for a considerable time after the close of the month to which they relate, the chart and text matter in connection therewith appear one year late.

In general, appropriate officials prepare the seven sections above enumerated; but *all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.*

The voluminous tables of data and text relative to local climatological conditions, that during recent years were prepared by the 12 respective "district editors," are omitted from the MONTHLY WEATHER REVIEW, but are collected and published by States at selected section centers. (See cover, p. 3.)

The data needed in Section 7 can not be collected and prepared until several weeks after the close of the month designated on the title-page; hence the REVIEW as a whole can not issue from the press until about eight weeks from the end of that month.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are specially due to the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.

The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, but such publication is not to be construed as official approval of the views expressed.

CORRIGENDUM.

REVIEW, June, 1918:
Page 291, column 2, table headed *Massachusetts, Cambridge,* "Howard" *should read* "Harvard."

SECTION 1.—AEROLOGY.

SOLAR AND SKY RADIATION MEASUREMENTS DURING JULY, 1918.

By HERBERT H. KIMBALL, Professor of Meteorology.

[Dated: Weather Bureau, Washington, D. C., Aug. 31, 1918.]

For a description of instrumental exposures, and an account of the methods of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, 1918, **46:2.**

The monthly means and departures from normal values given in Table 1 show that direct solar radiation averaged above normal at Madison, Wis., and slightly below normal at Washington, D. C., and Santa Fe, N. Mex., although at Washington the p. m. measurements averaged slightly above normal. At Lincoln, Nebr., due to a change in observers, but few measurements were obtained.

Table 3 shows a deficiency for the month at Lincoln of about 4.7 per cent, and only unimportant departures at Washington and Madison.

Skylight polarization measurements obtained on 5 days at Washington give a mean of 56 per cent with a maximum of 64 per cent on the 2d. Measurements on 10 days at Madison, Wis., give a mean of 65 per cent, with a maximum of 72 per cent on the 1st. These measurements are considerably above the July average for the respective stations.

TABLE 1.—*Solar radiation intensities during July, 1918.*

[Gram-calories per minute per square centimeter of normal surface.]

Washington, D. C.

Date.	Sun's zenith distance.									
	0.°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
	Air mass.									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
1918. A. M.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
July 1	1.38									
2	1.42	1.28	1.05	0.90	0.76	0.66				
3		0.99	0.89	0.79	0.65	0.55				
6		0.93								
8					0.90					
9	1.33	1.22	1.08	0.96	0.83	0.75	0.68	0.62		
15		1.12	1.01	0.90	0.81					
16	1.08	1.03	0.93	0.82	0.73	0.66				
20		0.88								
23			0.92							
24	1.18		0.85	0.78						
25		0.96	0.68	0.61						
Monthly means	**1.28**	**1.05**	**0.93**	**0.82**	**0.78**	**0.66**	**(0.68)**	**(0.62)**		
Departure from 10-year normal	**+0.02**	**−0.06**	**−0.04**	**−0.07**	**−0.07**	**−0.08**	**−0.02**	**−0.07**		
P. M.										
July 1		1.20	1.08	0.96	0.87	0.79	0.71			
2		1.25	1.13	1.04	0.97	0.88	0.79			
15			1.01	0.90						
Monthly means		**(1.22)**	**1.07**	**0.97**	**(0.92)**	**(0.84)**	**(0.75)**			
Departure from 10-year normal		**+0.15**	**+0.05**	**+0.07**	**+0.09**	**+0.05**	**±0.00**			

TABLE 1.—*Solar radiation intensities during July, 1918*—Continued.

Madison, Wis.

Date.	Sun's zenith distance.									
	0.°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°
	Air mass.									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
1918. A. M.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
July 1	1.45	1.34	1.26	1.18	1.10	1.02	0.96	0.89		
5	1.35									
6	1.32									
8	1.43									
10	1.40	1.27	1.15	1.08	0.99	0.91				
11	1.37				0.89					
12			1.14	1.04	0.95	0.86		0.77		
18		1.25	1.16	1.09	1.02	0.96	0.91			
19	1.28									
27	1.32	1.16			0.95					
29		1.30	1.21	1.13	1.04	0.96	0.89			
30	1.45	1.35		1.17	1.10	1.04	0.98			
31		1.33					0.97			
Monthly means	**1.37**	**1.29**	**1.18**	**1.12**	**1.00**	**0.96**	**0.94**	**(0.83)**		
Departure from 9-year normal	**+0.12**	**+0.17**	**+0.16**	**+0.17**	**+0.07**	**+0.05**	**+0.07**			
P. M.										
July 2		1.21								
5		1.16								
8		1.31								
19		1.02								
Monthly means		**1.18**								
Departure from 9-year normal		**+0.07**								

Lincoln, Nebr.

1918. A. M.										
July 1	1.43									
11	1.36									
19		1.13	1.01	0.95	0.85					
24							0.92			
31			1.09	1.04						
Monthly means	**(1.40)**	**(1.13)**	**(1.05)**	**(1.00)**	**(0.85)**		**(0.92)**			
Departure from 4-year normal	**+0.06**	**−0.07**	**−0.05**	**−0.02**	**−0.06**		**+0.11**			
P. M.										
July 1		1.20	1.07	0.97	0.88	0.79	0.72			
2		1.08	0.97	0.88	0.79	0.71				
11		1.12								
19				1.00	0.94	0.88				
Monthly means		**1.13**	**(1.02)**	**0.95**	**0.87**	**0.79**	**(0.72)**			
Departure from 4-year normal		**−0.07**	**−0.06**	**−0.03**	**−0.04**	**−0.05**	**−0.05**			

Santa Fe, N. Mex.

1918. A. M.										
July 9	1.40									
10		1.22	1.21	1.10	1.05	1.00				
11	1.36	1.25								
12		1.22								
13	1.43									
16	1.44	1.35	1.25	1.17	1.09					
17	1.45	1.33	1.25	1.18	1.12	1.06				
18	1.42	1.29	1.16	1.04						
19	1.43	1.27	1.18	1.09	1.01	0.95	0.91	0.85		
22	1.43		1.18							
23		1.32								
24			1.19							
25		1.23	1.11				0.81	0.75		
26	1.40		1.16							
29		1.29	1.18	1.07	0.91					
30		1.28	1.19	1.10	1.08		0.93			
31	1.39	1.25	1.12	1.05	0.97	0.91	0.85	0.79	0.74	
Monthly means	**1.42**	**1.28**	**1.18**	**1.10**	**1.03**	**0.98**	**0.88**	**0.80**	**(0.74)**	
Departure from 6-year normal	**±0.00**	**−0.02**	**−0.03**	**−0.05**	**−0.05**	**−0.06**	**−0.08**	**−0.06**		
P. M.										
July 23		1.26								
Monthly means		**(1.26)**								

TABLE 2.—*Vapor pressures at pyrheliometric stations on days when solar radiation intensities were measured.*

Washington, D. C.			Madison, Wis.			Lincoln, Nebr.			Santa Fe, N. Mex.		
Date.	8 a.m.	8 p.m.	Date.	8 a.m.	8 p.m.	Date.	8 a.m.	8 pm..	Date.	8 a.m.	8 p.m.
1918.	*mm.*	*mm.*	1918.	*mm.*	*mm.*	1918.	*mm.*	*mm.*	1918.	*mm.*	*mm.*
July 1	11.38	9.47	July 1	8.81	9.14	July 1	9.83	9.14	July 9	9.14	7.04
2	7.04	7.04	2	11.38	12.24	2	13.13	13.13	10	7.29	7.04
3	9.83	10.59	5	14.10	14.10	11	6.76	8.48	11	8.48	7.29
6	15.11	12.68	6	9.83	6.76	19	13.13	10.59	12	8.48	6.50
8	9.47	10.21	8	6.27	11.81	24	15.11	17.37	13	8.48	7.04
9	7.29	9.47	10	9.47	9.47	31	12.68	11.81	16	9.14	7.29
15	12.68	14.10	11	10.21	9.14	.....	.....	.....	17	6.27	4.75
16	15.11	14.60	12	10.21	9.14	.....	.....	.....	18	8.18	9.14
20	15.11	16.20	18	11.38	11.38	.....	.....	.....	19	9.14	10.07
23	16.79	16.79	19	13.13	14.60	.....	.....	.....	22	9.14	10.59
24	16.20	19.80	27	15.11	13.61	.....	.....	.....	23	9.14	7.57
25	17.96	14.60	29	11.81	10.21	.....	.....	.....	24	7.29	7.57
.....	.....	.....	30	7.57	7.57	.....	.....	.....	25	9.14	6.27
.....	.....	.....	31	7.04	7.57	.....	.....	.....	26	6.02	9.47
.....	.....	.....	.....	.....	.....	.....	.....	.....	29	8.48	8.48
.....	.....	.....	.....	.....	.....	.....	.....	.....	30	9.14	7.29
.....	.....	.....	.....	.....	.....	.....	.....	.....	31	8.81	9.14

TABLE 3.—*Daily totals and departures of solar and sky radiation during July, 1918.*

[Gram-calories per square centimeter of horizontal surface.]

Day of month.	Daily totals.			Departures from normal.			Excess or deficiency since first of month.		
	Washington.	Madison.	Lincoln.	Washington.	Madison.	Lincoln.	Washington.	Madison.	Lincoln.
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
July 1	690	626	767	181	80	187	181	80	187
2	730	645	742	222	100	162	403	180	349
3	643	322	681	136	−222	101	539	− 42	450
4	622	538	310	116	− 5	−270	655	− 47	180
5	306	666	474	−199	124	−106	456	77	74
6	608	673	322	103	133	−257	559	210	− 183
7	436	673	165	− 68	134	−413	491	344	− 596
8	393	737	708	−110	200	131	381	544	− 465
9	508	354	347	65	−182	−229	446	362	− 694
10	451	674	524	− 51	140	− 51	395	502	− 745
11	500	654	696	− 1	121	122	394	623	− 623
12	376	655	494	−125	124	− 79	269	747	− 702
13	338	407	400	−162	−123	−172	107	624	− 874
14	678	283	379	179	−245	−192	286	379	−1,066
15	653	85	395	154	−442	−175	440	− 63	−1,241
16	600	385	387	102	−139	−181	542	−202	−1,422
17	262	492	151	−235	− 29	−415	307	−231	−1,837
18	586	685	711	89	167	147	396	− 64	−1,690
19	354	596	695	−142	81	133	254	17	−1,557
20	557	616	710	62	104	150	316	121	−1,407
Decade departure							− 79	−381	− 662
21	618	597	634	124	88	76	440	209	−1,331
22	567	528	427	74	22	−129	514	231	−1,460
23	538	271	452	46	−232	−102	560	− 1	−1,562
24	485	253	709	− 6	−247	157	554	−248	−1,405
25	449	529	564	− 41	32	14	513	−216	−1,391
26	497	407	653	8	− 87	105	521	−303	−1,286
27	538	637	676	50	146	130	571	−157	−1,156
28	285	300	558	−202	−188	14	369	−345	−1,142
29	386	575	737	−100	90	195	269	−255	− 947
30	231	679	636	−254	197	96	15	− 58	− 851
31	129	645	562	−355	166	24	−340	108	− 827
Decade departure							−656	− 13	+ 580
Excess or deficiency since first of year						gr.-cal.	−932	+786	+ 672
						per cent.	−1.2	+1.0	+ 0.7

ABSORPTION AND RADIATION OF THE SOLAR ATMOSPHERE.[1]

By S. HIRAYAMA.

[*Reprinted from* Science Abstracts, Sect. A, June 29, 1918, §632.]

Computations of the transmission and radiation of the solar atmosphere by Schuster's method, using the recent measurements at the Smithsonian Astrophysical Observatory, are compared with the results given by Biscoe from the same material, but neglecting the effect of radiation of the solar atmosphere. The tables of residuals indicate that the observations are better represented than in Biscoe's table. The coefficient of transmission increases gradually with the wave length. The radiation due to the solar atmosphere is also tabulated; it is about one-third of the whole radiation for short wave lengths, and approaches to one-half as the wave length increases. Assuming the effective temperature of the sun to be 6,000° A., the temperature of the photosphere is calculated to be about 7,040° A., and that of the absorbing layer about 5,210° A.—*C. P. B[utler]*.

[1] Proc. Math. Phys. Soc., Tokyo, February, 1918, 9:236–240.

INTERNAL TEMPERATURES OF THE SUN.[1]

By A. VÉRONNET.

[*Reprinted from* Science Abstracts, Sect. A, June 29, 1918, §633.]

An investigation is made of the law of densities operating on a gaseous mass of similar nature and at the temperature of the sun, 6,000° A. The variation found would be about 22° per kilometer, indicating that at a certain depth a pressure of 11,000 atmospheres, and a maximum temperature of 60,000° A. would combine to confer on any gaseous masses the potentiality of explosive expansion which when released might produce the surface phenomena with which we are familiar.—*C. P. B[utler]*.

[1] Comptes Rendus, Paris, Jan. 21, 1918, 166:109–111.

HALO PHENOMENA OBSERVED DURING JULY, 1918.

By WILLIS RAY GREGG, Meteorologist.

[Dated: Aerological Division, Weather Bureau, Aug. 28, 1918.]

During recent years several brief studies of halos in relation to weather[2] have appeared in the MONTHLY WEATHER REVIEW, and, in addition, there have been published from time to time detailed descriptions, with sketches, of occurrences of the more unusual forms. There has been, however, no systematic observation and recording of halos in such manner as to render them readily susceptible of summarization and intercomparison, without considerable labor on the part of the investigator. Moreover, comparatively few exact readings of angular measurements have been made, and, as pointed out by Besson,[3] these measurements are of the utmost importance, particularly in the case of the circumhorizontal arc, tangent arcs of the 22° halo, and other rare forms.

The recent establishment of several aerological stations, well distributed with respect to latitude, longitude, and average cyclonic tracks, makes feasible the inauguration of a statistical study of these optical phenomena, not only with a view to determining the relative frequency of the various forms at different latitudes and by months and seasons and their relation to pressure distribution and precipitation, but also with the hope of adding to our knowledge concerning their angular measurements, distances from the sun or moon, etc. These stations are equipped with theodolites and smoked glasses and are located in country districts, where conditions for observation of this kind are at their best; moreover, the work of obtaining free air records is necessarily conducted in the open, thereby making it easy for observers to keep on the lookout for such phenomena. Accord-

[2] See "Selected Bibliography" at end of paper on "Further Study of Halos in Relation to Weather," by Howard H. Martin, MONTHLY WEATHER REVIEW, Mar., 1918, 46:120.

[3] Different Forms of Halos and their Observation, MONTHLY WEATHER REVIEW July 1914, 42:436–446.

ingly, suitable blank forms have been issued to these stations and to certain others, the observers at which have expressed a desire to cooperate, with instructions to forward each month, beginning with July, 1918, a report of the number of halos and associated forms observed, together with such measurements as were made; cloud, pressure, and precipitation notes, and sketches of any remarkable appearances. It is purposed to publish in each number of the MONTHLY WEATHER REVIEW a brief but sufficiently complete summary of the halos observed during that month. After a long series of such observations has been published, a more comprehensive summary and study of halos will be undertaken than has heretofore been possible.

The monthly summary for July, 1918, is given in t e following table:

TABLE 1.—*Halo phenomena observed during July, 1918.*

Station.	Altitude.	Latitude.	Longitude.	Date.	Form observed.	Time of—		Theodolite readings.					
						Beginning.	Ending.	Time.	Radius inside.	Radius outside.	Length of arc.	Distance from sun or moon.	Altitude of sun or moon.
	m.	° ′	° ′						°	°	°	°	°
Broken Arrow, Okla.*	233	36 02	95 49	5	Solar halo, 22°...	1:30 p. m.	2:55 p. m.	2:15 p. m.	20.5	22.0	27.0	.....	71.5
Cincinnati, Ohio	191	39 06	84 30	3	Solar halo, 22°...	11:40 a. m.	2:00 p. m.						
				21	Solar halo, 22°...	10:30 a. m.	11:15 a. m.						
				26	Solar halo, 22°...	6:45 a. m.	8:10 a. m.						
Dayton, Ohio	274	39 46	84 10	3	Solar halo, 22°...	11:15 a. m.	11:50 a. m.						
				4	Solar halo, 22°...	2:35 p. m.	2:50 p. m.						
				5	Solar halo, 22°...	10:15 a. m.	10:40 a. m.						
				21	Solar halo, 22°...	11:45 a. m.	12:30 p. m.						
Drexel, Nebr.*	396	41 20	96 16	None.									
Ellendale N. Dak.*	444	45 59	98 34	None.									
Groesbeck, Tex.*	141	31 30	96 28	None.									
Leesburg, Ga.*	85	31 47	84 14	None.									
Madison, Wis.	297	43 05	89 23	6	Solar halo, 22°...	11:10 a. m.	1:00 p. m.						
				12	Solar halo, 22°...	1:45 p. m.	2:00 p. m.						
				13	Solar halo, 22°...	9:00 a. m.	9:30 a. m.						
				17	Solar halo, 22°...	2:25 p. m.	9:00 p. m.						
				19	Solar halo, 22°...	3:30 p. m.	9:00 p. m.						
Nashville, Tenn	166	36 10	86 47	10	Solar halo, 22°...	4:15 p. m.	5:00 p. m.						
Royal Center, Ind.*	227	40 53	86 29	4	Solar halo, 22°...	7:10 a. m.	9:30 a. m.						
				18	Solar halo, 22°...	11:15 a. m.	12:10 p. m.						

Station.	Date.	Colors.**	Degree of brightness.	Clouds.			Station pressure.	Precipitation.	
				Amount.	Kind.	Direction.		Last previous ended.	First subsequent began.
Broken Arrow, Okla.*	5	O. Y	Dim	7	Ci. St	ne	Falling	D. N. a., 30th	5:35 a. m., 10th.
Cincinnati, Ohio	3	R. O. Y. G. V	Bright	10	Ci. St	nw	Stationary	4:40 p. m., 30th	8:44 a. m., 7th.
	21	R. O	Dim	3	A. St	w	Stationary	8:10 p. m., 16th	3:43 p. m., 22d.
	26	R. O. Y. G. V	Bright	8	Ci. St	nw	Stationary	8:35 a. m., 25th	1:41 p. m., 26th.
Dayton, Ohio	3		Dim	7	Ci. St	nw	Stationary	4:15 p. m., 30th	4:48 p. m., 5th.
	4		Dim	9	Ci. St	w	Falling	4:15 p. m., 30th	4:48 p. m., 5th.
	5		Dim	7	Ci. St	nw	Falling	4:15 p. m., 30th	4:48 p. m., 5th.
	21		Dim	6	Ci. St	w	Falling	11:35 a. m., 18th	6:50 a. m., 22d.
Drexel, Nebr.*	None.								
Ellendale, N. Dak.*	None.								
Groesbeck, Tex.*	None.								
Leesburg, Ga.*	None.								
Madison, Wis	6	O	Bright	2	Ci. St	w	Stationary	D. N. a., 5th	8:40 p. m., 6th.
				1	St. Cu	w			
	12	R	Dim	2	Ci. St	nw	Falling	7:00 p. m., 9th	2:12 p. m., 14th.
				2	Cu	nw			
	13	R	Bright	5	Ci. St	w	Stationary	7:00 p. m., 9th	2:12 p. m., 14th.
				4	A. Cu	s			
	17	R	Brilliant	9	Ci. St	nw	Stationary	6:42 p. m., 16th	10:33 a. m., 23d.
	19	R	Brilliant	2	Ci. St	nw	Stationary	6:42 p. m., 16th	10:33 a. m., 23d.
Nashville, Tenn	10	O	Dim	6	Ci. St	nw	Stationary	10:45 a. m., 8th	2:20 p. m., 16th.
				2	A. St	nw			
Royal Center, Ind.*	4	R. B	Dim	9	Ci. St	w	Rising	10:50 a. m., 2d	10:55 a. m., 5th.
	18	R. B	Bright	6	Ci. St	w	Falling	D. N. p., 16th	5:35 p. m., 23d.
				1	Ci	w			

* Aerological station.

** Beginning with part nearest sun or moon: R, red; O, orange, etc.

SECTION II.—GENERAL METEOROLOGY.

REPORT ON MODES OF AIR MOTION AND THE EQUATIONS OF THE GENERAL CIRCULATION OF THE EARTH'S ATMOSPHERE.

By GEORGE PORTER PAINE.

[Dated: University of Wisconsin, Madison, Wis., July 31, 1918.]

The object of the present investigation is to classify and to analyze fundamental modes of air motion and to ascertain some of the mathematical laws governing general circulation, a particular mode of motion in the earth's atmosphere.

The problems under consideration had their origin in the experiments of Osbourne Reynolds (**19–22**),[1] who demonstrated that the mean drift of a liquid in turbulent motion does not obey the laws expressed by the standard hydrodynamical equations. These equations are derived for the detailed motion of fluid elements under the assumption that the velocities and their space derivatives are so small that their powers and products may be neglected (**73**, p. 554). Reynolds obtained modified hydrodynamical equations expressing the average drift of the liquid, not in terms of the turbulent motion,[2] but in terms of mean values of functions of the deviations of the velocities of the fluid elements from the velocity of the average drift. These equations are open to the serious objection that they are obtained by applying the standard hydrodynamical equations to the detailed turbulent motions of the fluid elements, which motions in practice do not satisfy the conditions just stated upon which the validity of the hydrodynamical equations depends.

Clerk Maxwell (**91**, p. 81) demonstrated that, under certain conditions, the classical hydrodynamical equations expressed the laws governing the mass motion of a gas. Recent experiments [3] with the flow of gases in wide tubes and empirical studies of surface wind data [4] have shown that these equations not only fail to express the laws governing the turbulent flow of liquids but they also fail to express the laws governing the turbulent drift of the winds.

The reason for this apparent failure of the Kinetic Theory of Gases to account for observed air motions is to be found in the fact that the classical equations apply to the instantaneous air drift out of one fixed, microscopic volume element into another, while the motions that actually come under observation are in general of another and fundamentally different mode.

With a view to removing this difficulty, air motions are classified in the following pages in terms of mass motion, molecular motion, winds, and turbulence. Winds are classified with reference to their order, and turbulent motions, with reference to their order and to their kind.

Mathematical expressions for mass motion and for molecular motion are already available from the standard Kinetic Theory of Gases, but, strange as it may seem, no attempt appears to have yet been made to formulate mathematical expressions descriptive of *winds* and of *turbulent motion*. In other words, no definitions of these fundamentally important modes of motion have been proposed which possess a degree of precision sufficient for the application of the methods of Mathematical Physics to the study of the circulation of the atmosphere.

Winds have accordingly been defined with precision in the present article in terms of multiple mean-value integrals. These integrals are built up from certain fundamental concepts of classical gas theory. The idea of wind order is suggested immediately by this definition, and the quantitative definitions of turbulence and of orders of turbulence grow out of the integral expressions for winds and the idea of wind order.

These definitions, on the one hand, are expressed in terms of Mathematical Analysis. On the other hand, they describe with precision observed phenomena as yielded by instrumental observations.

Having set up these analytical definitions of fundamental modes of air motion and established their correspondence to observed phenomena, it is here shown that equations for the winds of the general circulation follow as an extension of the classical Kinetic Theory of Gases.

Mass motion.—Confining the present investigation to the motions of the earth's atmosphere below about 80 kilometers elevation (**101**, pp. 1–29), we have to deal with an aggregation of molecules, chiefly of two kinds—nitrogen and oxygen. According to the Kinetic Theory of Gases, each one of these molecules describes a rectilinear free path with uniform velocity, until it encounters one or more neighboring molecules, when it starts off in a new direction at a different speed. For example, at 0° C. and under a pressure of one atmosphere the number of molecules in one cubic centimeter of air is about 2.75×10^{19}. The mean length of the free paths is about 1.42×10^{-5} cm. At 15° C., the mean velocity of the molecules is about 459 meters per second, and the range of velocities represented at any instant by the individual molecules is very great. The number of encounters per second in one cubic centimeter is of the order of 1.64×10^{29}.

To investigate the motion of this complicated dynamical system, it is usual to regard the space occupied by the air as divided into a great number of cells. These cells are fixed in space and are small compared with the total volume occupied by the gas. A typical cell is chosen as a region for investigation. At a given instant the velocity of each of the swarm of molecules then occupying the cell is supposed to be ascertained. The numerical mean of all these velocities is then computed, and the result is a measure of the tendency of the molecules to drift collectively out of one cell into another. In other words, the numerical mean measures the *mass motion* of the gas in the cell.

Evidently the character of the mass motion corresponding to a given state of motion of the molecules depends upon the size arbitrarily assigned to the fixed cells. If we suppose the cells all alike, and denote their common volume by $d\tau$, then $d\tau$ should satisfy the following conditions:

(*a*) It should be large compared with the mean free path of the molecules.

[1] NOTE.—References are denoted by their serial number in the bibliography at the end of this paper.
[2] See definition, p. 315.
[3] See references cited relative to kinetic turbulence, p. 315.
[4] **70,84, 71, 72, 94, 95, 99.**

(*b*) It should be so small that the molecular density is practically uniform throughout each cell.

The position of any of one these microscopic cells, or volume elements, may be indicated by the coordinates of its middle point P. We shall refer to the mass motion in this cell as the *mass motion at point P*.

The temperature and the hydrostatic pressure of classical gas theory are essentially numerical means computed for the molecules occupying a specified cell at a given time; and molecular density is explicitly defined as the number of molecules in the cell under consideration, divided by its volume. The temperature, the hydrostatic pressure, and the density of the atmosphere may therefore be regarded as phases of mass motion.

Integral expressions for mass motion.[5]—In terms of Mathematical Analysis, the mass motion of a gas can be described with precision. Let x, y, and z be the coordinates, referred to fixed axes, of a point within a fixed volume element $d\tau$, and let $\nu\ (x, y, z, t)$ be the molecular density in this element at a given instant t. Imagine the velocity diagram of the Kinetic Theory of Gases constructed for all the molecules in $d\tau$ at the instant t. The molecular velocities in $d\tau$ are supposed to vary from molecule to molecule through all possible values. It is usual in works on the Kinetic Theory of Gases to select from the molecules in $d\tau$ at instant t all those whose velocities lie in a range

$$\left.\begin{array}{l} u \text{ and } u+du \\ v \text{ and } v+dv \\ w \text{ and } w+dw \end{array}\right\} \quad \text{(A)}$$

which molecules we shall designate as molecules of class A, and to define a function $f\,(u, v, w, x, y, z, t)$ as such that the number of molecules of class A in $d\tau$, at instant t, is

$$\nu\ (x, y, z, t)\, f\ (u, v, w, x, y, z, t)\ d\varpi d\tau \qquad (1)$$

where

$$d\varpi = dudvdw$$

and is the volume element corresponding to class A in the velocity diagram. If u, v, and w are the velocity components of an individual molecule in a cell whose center is $P\ (x, y, z)$, and if $\varphi\ (u, v, w)$ is a function depending on them,[6] then, with the aid of the foregoing definition, the numerical mean of φ for all the molecules in the volume element $d\tau$ may be expressed by the relation

$$\varphi_0 = \frac{1}{\nu d\tau}\Sigma\varphi\nu f d\varpi d\tau$$

where the summation is effected for the velocities of all the molecules in $d\tau$. Approximately,

$$\varphi_0 = \frac{1}{\nu d\tau}\int_{-\infty}^{+\infty}\varphi\nu f d\varpi d\tau = \int_{-\infty}^{+\infty}\varphi f d\varpi \qquad (2)$$

Thus, for example, the x-component of the velocity of mass motion is

$$u_0 = \int_{-\infty}^{+\infty} u f d\varpi$$

A numerical mean is in general a function of the time.

[5] For the sake of brevity, the expressions here given apply to a single gas. They may, however, be extended to apply to a mixture of gases having different molecular weights.

[6] For example, u^2, or uv or uv^2.

Molecular motion.—Deviations of the motions of individual molecules from the mass motion give rise to another mode of motion. Let u, v and w be the velocity components of an individual molecule in a fixed volume element $d\tau$ at the instant t, and let u_0, v_0, and w_0 be the numerical means of the corresponding velocity components of all the molecules in that cell at the same instant; then the velocity whose components are U, V and W which is defined by the relations

$$u = u_0 + U,\ v = v_0 + V,\ w = w_0 + W \qquad (3)$$

is called the *molecular velocity* of the molecule under consideration.

Mean-value properties of mass motion.—If φ of equation (2) is now set successively equal to u, v, and w, then the resulting numerical means are equal respectively to the velocity components of the mass motion of the gas. Considerable information regarding these means is available from the Kinetic Theory of Gases. For example, in the integral

$$(\varphi_0)_0 = \int_{-\infty}^{+\infty}\varphi_0 f d\varpi \qquad (4)$$

the summation is effected for all the molecules in the volume element $d\tau$. But φ_0 is the same for all the molecules in $d\tau$, hence[7]

$$(\varphi_0)_0 = \varphi_0\int_{-\infty}^{+\infty} f d\varpi = \varphi_0 \qquad (5)$$

From this relation and (3), we have

$$U_0 = V_0 = W_0 = O \qquad (6)$$

consequently

$$\left.\begin{array}{l} (u^2)_0 = u^2{}_0 + (U^2)_0 \\ (v^2)_0 = v^2{}_0 + (V^2)_0 \\ (w^2)_0 = w^2{}_0 + (W^2)_0 \end{array}\right\} \qquad (7)$$

and

$$\left.\begin{array}{l} (uv)_0 = u_0v_0 + (UV)_0 \\ (vw)_0 = v_0w_0 + (VW)_0 \\ (wu)_0 = w_0u_0 + (WU)_0 \end{array}\right\} \qquad (8)$$

Assuming, as a first approximation, that the law of equipartition of energy

$$(U^2)_0 = (V^2)_0 = (W^2)_0 \qquad (9)$$

holds for the molecules which at any instant are in a given volume element $d\tau$, it can be shown that in $d\tau$,

$$\left.\begin{array}{l} (UV)_0 = -\dfrac{\kappa}{\rho}\left(\dfrac{\partial v_0}{\partial x} + \dfrac{\partial u_0}{\partial y}\right) \\ (VW)_0 = -\dfrac{\kappa}{\rho}\left(\dfrac{\partial w_0}{\partial y} + \dfrac{\partial v_0}{\partial z}\right) \\ (WU)_0 = -\dfrac{\kappa}{\rho}\left(\dfrac{\partial u_0}{\partial z} + \dfrac{\partial w_0}{\partial x}\right) \end{array}\right\} \qquad (10)$$

where κ corresponds to the viscosity coefficient of the Theory of Continuous Media, and ρ is the volume density of the gas.

It should be observed that the assumption of the law of equipartition of energy applies here to deviations from

[7] The total number of molecules in $d\tau$ is $\nu d\tau\int_{-\infty}^{+\infty} f d\varpi$; but the total number is also given by $\nu d\tau$; hence $\int_{-\infty}^{+\infty} f d\varpi = 1$.

numerical averages taken over any one of the very small volume elements under consideration, and not to deviations from numerical averages taken over large masses of the atmosphere.

The hydrostatic pressure p of the gas is defined as

$$p=\frac{\rho}{3}(U^2+V^2+W^2)_o \quad \text{.....(11)}$$

and the temperature T is given by the equation

$$T=\frac{1}{3H}(U^2+V^2+W^2)_o \quad \text{.....(12)}$$

in which H is the constant of the characteristic equation of the gas.

The equations of mass motion.—In the Kinetic Theory of Gases, it is also shown that by means of a study of the flux of matter, of momentum, and of kinetic energy, as governed by the fundamental laws of dynamics, a system of equations may be deduced for the mass motion of a gas. The results depend on the foregoing mean value properties of mass motion.

The dynamical equations.[8]—The analytical statement of the law of conservation of matter takes the form of the *equation of continuity:*

$$\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u_o)}{\partial x}+\frac{\partial(\rho v_o)}{\partial y}+\frac{\partial(\rho w_o)}{\partial z}=O \quad \text{.....(13)}$$

and the law of conservation of momentum is expressed by the three *momentum equations*:[9]

$$\left.\begin{aligned}\frac{du_o}{dt}&=X-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\epsilon}{3}\frac{\partial\theta_o}{\partial x}+\epsilon\Delta u_o\\ \frac{dv_o}{dt}&=Y-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\epsilon}{3}\frac{\partial\theta_o}{\partial y}+\epsilon\Delta v_o\\ \frac{dw_o}{dt}&=Z-\frac{1}{\rho}\frac{\partial p}{\partial z}+\frac{\epsilon}{3}\frac{\partial\theta_o}{\partial z}+\epsilon\Delta w_o\end{aligned}\right\} \quad \text{.....(14)}$$

The thermodynamical equations.—The *characteristic equation* of the gas is

$$p=\rho HT \quad \text{.....(15)}$$

Finally, the law of conservation of energy yields the *energy equation:*

$$\frac{\vartheta}{\rho}\Delta T+\frac{1}{\rho}\mathfrak{G}=c_v\frac{dT}{dt}+\tfrac{2}{3}c_v\theta_o+\frac{\epsilon}{J}W \quad \text{.....(16).}$$

[8] First derived from gas theory considerations by Maxwell, see **91**, p. 81.

[9] *Notation.*—(X, Y, Z) is the resultant of the body forces per unit mass.
T is the temperature, measured on the absolute scale.

$\frac{d}{dt}=\frac{\partial}{\partial t}+u_o\frac{\partial}{\partial x}+v_o\frac{\partial}{\partial y}+w_o\frac{\partial}{\partial z}$.

$\theta_o=\frac{\partial u_o}{\partial x}+\frac{\partial v_o}{\partial y}+\frac{\partial w_o}{\partial z}$, which is analogous to the time rate of cubical dilitation in the case of the motion of a continuous medium.

$\Delta=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}$, the Laplacian operator.

κ is analogous to the viscosity coefficient of a continuous medium.
ϑ is the coefficient of conduction of heat for the gas.
c_v is the specific heat of the gas at constant volume.
H is the gas constant in the characteristic equation of the gas.
J is the mechanical equivalent of heat.

$\epsilon=\frac{\kappa}{\rho}$.

$\mathfrak{G}$ is the gain in energy per unit volume due to absorption and emission of radiation.

$$W=\tfrac{2}{3}\theta_o^2-\left[\left(\frac{\partial v_o}{\partial x}+\frac{\partial u_o}{\partial y}\right)^2+\left(\frac{\partial w_o}{\partial y}+\frac{\partial v_o}{\partial z}\right)^2+\left(\frac{\partial u_o}{\partial z}+\frac{\partial w_o}{\partial x}\right)^2\right]$$
$$-2\left[\left(\frac{\partial u_o}{\partial x}\right)^2+\left(\frac{\partial v_o}{\partial y}\right)^2+\left(\frac{\partial w_o}{\partial z}\right)^2\right],$$

which is twice Stokes' dissipative function for a continuous medium.

Space derivatives of the temperature and of the velocities.—Very little is now known regarding the magnitudes of the space derivatives of the temperature and of the velocities of the mass motion of the earth's atmosphere, as compared with the magnitudes of the "gradient" and body forces[10] which give rise to that motion. This much, however, seems certain, that for mass motion in the neighborhood of an obstacle or near the ground where cross currents and eddies prevail, these derivatives may be relatively large, and hence by no means negligible for purposes of approximation.

Mass motion and observed phenomena.—The validity of equations (14), in so far as they express the laws governing lamellar (nonturbulent) gas motions, has been abundantly established by experimentation.[11] At the same time, observation and experiment have demonstrated that they fail to express the laws governing those turbulent, eddying, tumultuous motions characteristic of the circulation of the atmosphere.[12]

Notwithstanding this notable failure, the mathematical investigation of air motions had not been extended beyond the foregoing classical analysis of mass motion until, through the researches leading to the present report, it became evident that the apparent breakdown of the equations of mass motion was due to the fact that, on the one hand, the mass motion of the atmosphere can not generally be observed by ordinary methods, and, on the other hand, the modes of motion actually observed and recorded by the Government observers and others are not mass motions but *time means of mass motions, averaged over intervals ranging from a few seconds to a long period of years.*

Evidence of this fundamental and important fact will be brought forward in the course of the ensuing discussion of winds and turbulence. Meanwhile, we proceed to the following analytical definition of a wind.

Definition of a wind.—Let φ_o be any one of the mass motion variables u_o, v_o, w_o, p, ρ, or T, and let $\mathfrak{T}$ be a fixed, definite interval of time. Then the time mean of φ_o extended over the interval $\mathfrak{T}$ is given by

$$\bar{\varphi}_o=\frac{1}{\mathfrak{T}}\int_{t-\mathfrak{T}/2}^{t+\mathfrak{T}/2}\varphi_o dt \quad \text{.....(17)}$$

If φ_o is one of the velocity components u_o, v_o, or w_o, then the time mean takes the form of the double mean-value integral

$$\bar{\bar{\varphi}}_o=\frac{1}{\mathfrak{T}}\int_{t-\mathfrak{T}/2}^{t+\mathfrak{T}/2}\int_{-\infty}^{+\infty}\varphi f d\varpi dt \quad \text{.....(18)}$$

The collective mean-value phenomena of velocity, pressure, temperature, and density, as defined by relations (17) and (18), will be said to constitute a *wind of order* $\mathfrak{T}$.

Observed phenomena and the integral expressions for a wind.—The classical Kinetic Theory of Gases, as we have seen, treats of mass motion and the molecular motion accompanying it, and it has in general been tacitly assumed that observations made in the ordinary way with standard meteorological instruments represent the mass motion of the air. But this assumption clearly does not accord with the facts. An ideal anemometer, for

[10] The "gradient" force is the force per unit mass whose components are given by the pressure terms of equations (14). The body forces (X, Y, Z) of equations (14) are the forces per unit mass due to gravitational and electromagnetic fields existing in the region occupied by the atmosphere.

[11] See, for example, **62, 63, 64, 65, 66, 67, 68, 69, 96.**

[12] **70, 71, 72, 6, 12.**

example, so minute as to be contained in one of the elementary cells $d\tau$ (see p. 311), so designed as to set up no extraneous disturbances, and so sensitive as to respond instantly to the most rapid or minute fluctuations of the air, would measure the air drift in the cell $d\tau$, that is to say, the velocity of the mass motion as defined by equation (2).

The standard Robinson anemometer occupies a relatively large space, it sets up eddies and cross currents in its neighborhood, it fails to respond to rapid or minute fluctuations of the air (**1**, **100**, **61**), and its moment of inertia is so large that, on gusty days, it constantly lags or overruns.

Only approximately, therefore, does the frequency of revolution of the whirling cups indicate the true mass motion which, if the anemometer were removed, the air would have in the cell $d\tau$ at the center of the instrument.

In practice, however, the detailed frequency variations of the instrument are not ascertained. The data are obtained by counting the number of notches appearing per specified time upon the record sheet.

Subject, then, to errors due to (*a*) the large size of the instrument, (*b*) the disturbances which it sets up, (*c*) its failure to respond to rapid and minute fluctuations, and (*d*) its tendency to lag during sudden gusts and to overrun during sudden calms, actual readings of the anemometer indicate for specified values of $\mathfrak{T}$, time means of the mass motion of the air in the neighborhood of the instrument, in the sense denoted by the multiple mean value integral (18).

When the air is in motion, the conditions are very much the same in the case of the standard thermometer. An ideal, microscopic thermometer, suspended in a cell $d\tau$, creating no extraneous disturbances, and quick and sensitive enough to yield readings proportional to the most rapid and minute variations of the mean kinetic energy of the molecular motion in that cell, would register the temperature of the air as defined by equation (12).

The large size of the standard thermometer compared with $d\tau$, the eddies it sets up, its sluggish reactions and its inability to respond to minute temperature variations (**2**) must greatly impair the accuracy with which the variations of the instrument indicate the actual fluctuations of the temperature.

Unlike the anemometer, the thermometer yields, from a single reading, not a definite time mean, but a time mean corresponding to some indeterminate and unspecified value of $\mathfrak{T}$, varying from reading to reading, and depending partly on the reaction constants of the instrument, and partly on the observer.

When mean temperatures are obtained by averaging such readings over fixed, definite, and specified values of $\mathfrak{T}$ (daily means, annual means, etc.) then, subject to the errors described, they yield the wind temperatures defined by the integral expression (17).

It is essential to observe that instrumental errors in wind velocity and temperature, due to the causes enumerated, pertain to *the mass motion of classical gas theory* and not to the time means discussed in this paper. The latter can be computed with precision.[13]

The dependence of winds corresponding to a given mass motion upon the values assigned to $\mathfrak{T}$.—Fifteen readings of a Robinson anemometer, at Madison, Wis., on August 26, 1897, are represented in figure 1. The velocities having been obtained by counting the number of notches appearing per hour on the record sheet, the interval $\mathfrak{T}$ for these observations was one hour. Figure 2 shows the wind velocity at the same station, but averaged for each

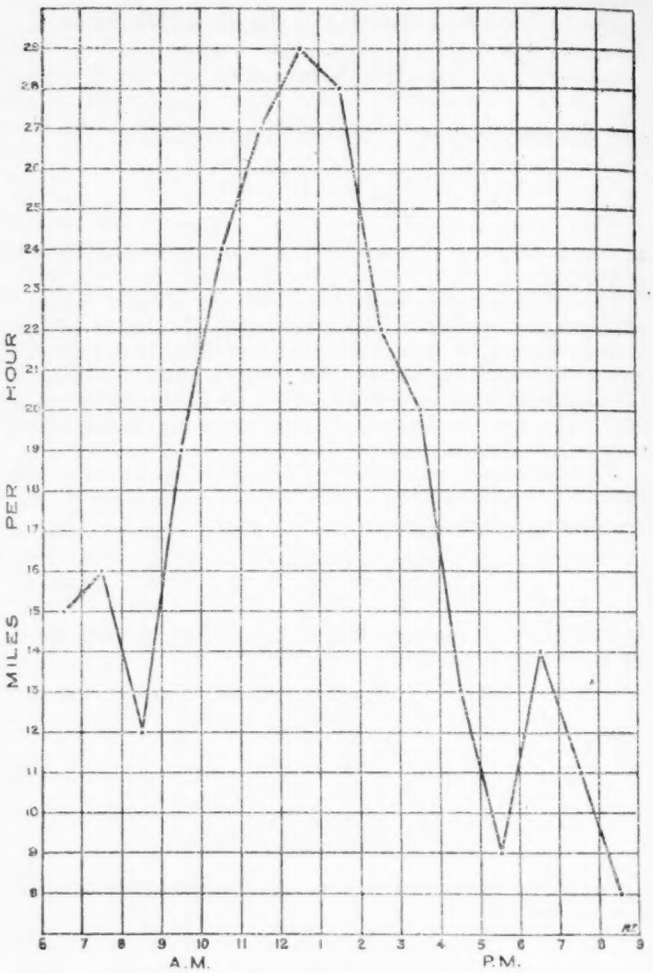


FIG. 1.—Wind velocity at Madison, Wis., August 26, 1897. $\mathfrak{T}$=1 hour.

month of the year 1897, twelve mean values for which $\mathfrak{T}$ was one month. The yearly mean wind velocities for the years 1894 to 1903, inclusive, are shown in figure 3. In

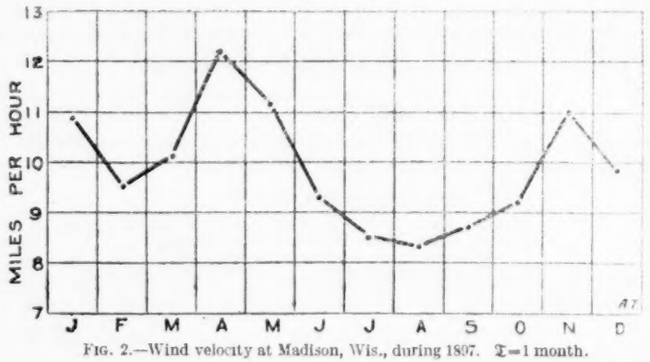


FIG. 2.—Wind velocity at Madison, Wis., during 1897. $\mathfrak{T}$=1 month.

this case $\mathfrak{T}$ was one year, each mean having been computed from data obtained during the interval between January 1 and December 31 of the year under consideration. Ten mean values are plotted in figure 4, for which

[13] The dynamical significance of the barometer is briefly discussed in footnote to page 321.

$\mathfrak{T}$ was thirty years; that is to say, the mean wind velocity was found from anemometer readings extending fifteen

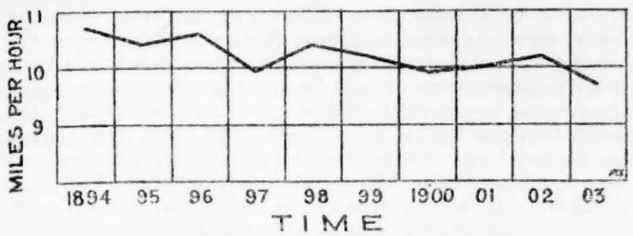


FIG. 3.—Wind velocity at Madison, Wis., 1894–1903. $\mathfrak{T}$=1 year.

years before and after the year for which the mean was computed.[14]

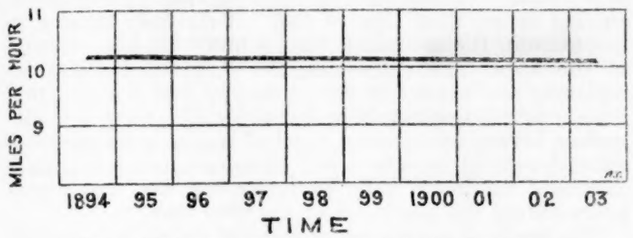


FIG. 4.—Wind velocity at Madison, Wis., 1894–1903. $\mathfrak{T}$=30 years.

For purposes of comparison, these four graphs should be drawn to the same scale. Thus, for example, if variations of the type shown in figure 1 were plotted to the scale of figures 3 and 4 over the entire period of ten years, the resulting graph would have the appearance of *a continuous band nearly seventeen units broad*. The extreme mutual divergence of these winds is apparent.

Unfortunately, wind direction data, as now recorded, do not afford material for the construction of stream-line charts for *winds* in the sense in which that term is here used. At the same time, it is unquestionably true that stream lines, like velocities, exhibit a fundamental difference in the character of the winds corresponding to the same mass motion but to different values of $\mathfrak{T}$.

The same phenomenon is observable in atmospheric temperatures and pressures (**2**).

It may therefore be stated as a general principle, that the character of a wind corresponding to a given mass motion is, in general, profoundly affected by the value arbitrarily assigned to the time interval $\mathfrak{T}$.

From this principle it follows that no specific problem in wind motion can be regarded as formulated, unless the order of the wind under consideration be explicitly defined.

Turbulent motion.—It will be observed that in taking the monthly averages for figure 2, the characteristic irregularities of the wind velocities of figure 1 are largely smoothed out; and that in taking the yearly averages for figure 3, not only the characteristic irregularities of the wind velocities of figure 1, but those of figure 2 are smoothed out also. The averaging process corresponding to figure 4, for which $\mathfrak{T}$ was thirty years, had the effect of practically obliterating all irregularities, so that the graph appears as a straight line nearly parallel to the axis of abscissas.[15] The situation is in general the same relative to pressure curves, stream lines, etc. There are cases, however, where the mean motion does not change with $\mathfrak{T}$. If, for example, the wick of a kerosene lamp be adjusted to give a steady flame without smoking, stream lines in the chimney for five-minute averages differ very little from stream lines for five-second averages. But when the motions differ for different values of $\mathfrak{T}$, it is essential to distinguish clearly between them. This can be accomplished analytically by means of the two following definitions.

(*a*) A wind of order $\mathfrak{T}$ may be described in terms of *time curves* representing the velocity, pressure, temperature and density at a single station during a given period of time; or else by a *weather map* showing stream lines, isobars, isotherms and lines of constant density drawn over a given region for a single instant of time.

(*b*) Given an air mass, the molecules of which are in a given state of motion M. Suppose that a $\left\{\begin{matrix}\text{set of time curves}\\ \text{weather map}\end{matrix}\right\}$ S be constructed representing the motion M for time means extended over an interval $\mathfrak{T}$. If another $\left\{\begin{matrix}\text{set of time curves}\\ \text{weather map}\end{matrix}\right\}$ S_1 be constructed representing the motion M, but for time means extended over a shorter interval $\mathfrak{T}_1$, then, provided the $\left\{\begin{matrix}\text{curves}\\ \text{map}\end{matrix}\right\}$ S_1 be different from the $\left\{\begin{matrix}\text{curves}\\ \text{map}\end{matrix}\right\}$ S, the motion S_1 will be said to be *turbulent relative to the motion S*.

Turbulence of different orders.—The order n of the turbulent motion S_1 relative to S will be defined as

$$n=\frac{\mathfrak{T}}{\mathfrak{T}_1} \qquad (18a)$$

Figure 2, for example, shows turbulence of order 12 relative to the wind defined for annual means. Figure 1 shows turbulence of order 8,760 relative to the wind defined for annual means, and of order 262,800 relative to the wind defined for 30 year means.

Kinetic turbulence.—Let us return to the illustration of the kerosene lamp. By properly adjusting the flame, stream lines for half second averages can be made smooth; in which case the draft is good, and the lamp burns without smoking. Turn the wick up, and the draft, or *wind*, is accelerated, until what seems a critical velocity is attained, at which the stream lines become unstable, winding themselves into a tangle revealed by spirally curling smoke jets due to imperfect combustion. The imperfect combustion is in turn due to decreased draft, some of the kinetic wind energy having gone into the production of turbulence.

A great deal of experimental work has been done on turbulence of this kind, in both liquids and gases. Some of the testimony relative to critical velocities is conflicting, and the character of the stream lines and the origin of the motion itself are little understood.[16]

The first researches in kinetic turbulence seem to have been made in 1883 by Osbourne Reynolds (**19–22**), whose notable experiments with liquids revealed clearly the complicated character of the secondary stream lines often associated with a general drift or mean motion. For slow motions, the stream lines indicated the well-known Poisuille *régime* (**18**); but mean motion accelerations led to more or less abrupt appearances of exceedingly complex stream-line configurations which, super-

[14] See formula (18).

[15] The apparent slope of the curve of fig. 4 is discussed on p. 317, note 24.

[16] **2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12; 13, No. 3; 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26; 93. p, 776; 94, 95, 99, 103.**

posed on the general drift, absorbed much of its kinetic energy.

Much stress was laid by Reynolds on the abruptness of the transition from the Poisuille *régime* to turbulent motion, but more recent researches, in particular those of Ekman (**5**) in 1907, seem to indicate that those changes, occurring at certain "critical velocities," were due to fortuitous disturbances set up by the apparatus. This, however, is of secondary importance. What Reynolds demonstrated was that, except in the case of slow motions, the general drift defined by time means was accompanied by superimposed turbulence, and that the former was profoundly affected by the latter. From the point of view of the present paper, Reynolds's turbulence was a mean motion corresponding to a value of $\mathfrak{T}$ considerably less than the order of the general drift.

In gases, related phenomena have been studied experimentally by Becker (1907), Fry and Tyndall (1911), Dowling (1912), Kohlrausch (1914), Zemplén (1912), and others. The experiments of Kohlrausch (**12**) are of particular interest, as showing clearly a deep-seated retarding influence at work after the transition from the Poisuille to the turbulent *régime*.

A large proportion of experimentation in air turbulence has been confined to the investigation of critical velocities, several of which have sometimes been observed in connection with a single type of apparatus. Zemplén's (**25**, p. 71) experiments with spherical gas layers have, however, indicated that the abrupt appearance of turbulence upon the attainment of certain critical velocities was probably due to disturbances set up by the ends of the tubes through which the gas was driven.

Varied and in some respects conflicting as the data seem to be, the following generalizations seem to have been empirically established. (*a*) Turbulence of the kind under consideration appears in the neighborhood of obstacles, material boundaries and surfaces of discontinuity, and in general where high differential velocities exist between adjacent fluid strata. (*b*) It may appear where the material boundaries and the adjacent fluid strata are at the same temperature. (*c*) A wind of order $\mathfrak{T}$ is in general modified profoundly by the occurrence of superimposed gusts, cross currents, and eddies—turbulent motions relative to $\mathfrak{T}$. In particular, a turbulent wind does not obey the laws expressed by equations (13) to (16) governing the mass motion of the gas.[17] On account of the first two of the foregoing generalizations, the kind of turbulence under consideration will be referred to as *kinetic turbulence*.[18]

The results stated in the last paragraph have been derived from observation and experiment. Reynolds and Lorentz (**19-22**), (**13**) have shown from theoretical considerations why the hydrodynamical equations do not govern the mean motion, or average drift, of a turbulent liquid. In the present paper it is shown from theoretical considerations why the equations of mass motion (13) to (16) do not govern a turbulent wind, defined for large values of $\mathfrak{T}$.

Convective turbulence.—A stream of water at 20°C. and flowing rapidly down an inclined iron trough at the same temperature, will exhibit turbulence relative to a general drift corresponding, say, to hourly means. If the temperature of the trough be sufficiently increased, the water will boil as it descends, and the turbulence will thus be enormously complicated by the appearance of a new type of stream-line irregularities. Such irregularities, which are due to temperature differences between material boundaries and their adjacent fluid strata, occur in the lower layers of the atmosphere and operate powerfully to modify atmospheric stream lines. On a fair summer day the process is generally visible. During the morning, the earth becomes hotter than the adjacent air, and heat is conducted from the ground to the lowest air stratum. The resulting vertical instability manifests itself in multitudinous flickering jets rising from the ground. Although these jets are visible only to the height of a few feet, the appearance of cumulous clouds bears witness to the fact that the jets are uniting into massive convection columns which are driven upward to an altitude of perhaps a mile. The structure of higher order surface winds is profoundly complicated by these enormous air columns cutting across their lines of flow. Relatively lacking in momentum, the ascending masses mix with the currents of the upper air, while irregular downward draughts, replacing the thermally driven masses and transmitting horizontal momentum from the upper air currents to the surface layers, unite into a wind of higher order near the ground, which, making itself first felt in the morning, attains a maximum velocity during the day, and disappears during the late hours of the afternoon.[19]

This mode of motion, *convective turbulence*, is characteristic of regions where the material boundaries and the adjacent air strata are at different temperatures. It accordingly differs essentially from kinetic turbulence with regard to its origin; possibly also with regard to characteristic stream-line configurations.

Combined effects of kinetic and convective turbulence.—Fair weather convection, as we have seen, affords an illustration of convective turbulence relative, for example, to a wind defined for daily averages. Local thunderstorms furnish another example. Both, of course, are complicated by the action of water vapor. The HIGHS and LOWS of the daily weather maps reveal turbulence relative to monthly and yearly means. Some of these disturbances, like the Arizona LOW of the summer months, belong clearly, at least in their incipient stages, to the convective class. Others seem to be purely kinetic in their origin. The fitful and intermittent gusts of the substratosphere[20] are doubtless of the same character. Probably most of the turbulence phenomena (relative to yearly means) depicted on the daily weather maps are resultants of both kinds of turbulent motion. In fact it is by no means possible in atmospheric phenomena near the ground to distinguish between irregularities of the two sorts. Observational studies of turbulence in the lower layers of the atmosphere unquestionably pertain to a mixture of the two. Lilienthal's (**61**, p. 77) studies carried on with vertical recording systems of parallel wind vanes revealed marked turbulence in winds of order ranging from three to six seconds. It was found that winds in passing over a wood or a hill sent great eddies upward. The pronounced and almost abrupt upward motions usually seen to accompany the mean drift of smoke jets from tall, isolated factory chimneys were shown to be due, not to the heated condition of the escaping gases, but to characteristic upward irregularities of wind motion near the ground. Similar phenomena were observed and studied by Langley (**1**), whose measurements with sensitive, light-weight anemometers revealed marked turbulence in winds defined

[17] See **19-22**, **13**, **8**, **71**, **72**, and standard works dealing with the flow of fluids through pipes, weirs, canals, etc.

[18] Regions of turbulence in the atmosphere are sometimes bounded by surfaces along which the wind is discontinuous. Some of the more important memoirs relating to surfaces of discontinuity are the following, arranged here in chronological order: **53**, p. 310; **52**, **39**, **46**, **50**, **55**; **43**, p. 146; **28**, **40**, **41**, **42**, **38**, **48**, **45**, **27**, **49**, **29**, **47**, **30**, **54**, **31**, **32**, **33**, **34**, **44**, **35**, **37**, **36**, **51**, **89**, **104**. Reference **92**, p. 107, is of interest in connection with **45**. An admirable summary and extensions of the theory are contained in **98**.

[19] See **102** and **99** on the diurnal variation of the wind.

[20] **56**, p. 165; **57**, p. 214; **58**, p. 153; **59**, p. 26; **60**.

for $\mathfrak{T}$-intervals of from four to ten minutes. Barkow (**2**; see also **90**) showed that turbulence of the same order reveals itself in temperature and pressure graphs. But in the results of observation there is generally little or nothing to enable one to distinguish between kinetic and convective turbulence. Near the earth the two phenomena combine to the extent that the atmosphere has well been called a "treacherous sea," where irregular cross currents and eddies, violent swirls and sudden side gusts prevail.[21]

That the two kinds of turbulence are, however, essentially different seems to be indicated by the form of the equations of general circulation (45) to (50).

Mean value properties of winds.—Let α represent any one of the six mass motion variables u_o, v_o, w_o, p, ρ and T. Deviations of the mass motion α [22] in any volume element $d\tau$ from a wind due to α and defined in terms of an interval $\mathfrak{T}$ [23] are given by the relation

$$\alpha=\bar{\alpha}+\alpha' \quad \text{.....(19)}$$

As was pointed out in the discussion of turbulent motion, *the larger the value of* $\mathfrak{T}$, *the more nearly the corresponding wind approximates a state defined by the relation*

$$\frac{\partial\bar{\alpha}}{\partial t}=0 \quad \text{.....(20)}$$

This general principle is assumed here as a fundamental hypothesis. It is well illustrated by the wind velocities represented in figures 1 to 4. The great irregularities shown in figures 1, 2, and 3 disappear in figure 4, which is in fact a straight line, approximately parallel to the time axis.[24] Figure 4 therefore indicates that the mean velocity for 30-year averages satisfies relation (20) throughout the 10-year interval represented.

This relation is a sufficient condition for a steady state of the mean motion $\bar{\alpha}$. But this is by no means tantamount to saying that the wind thus defined is a *steady wind*, as that term is ordinarily used. Quite the contrary winds of 30-year order are in general turbulent. Shorter $\mathfrak{T}$-intervals for the same mass motion, as illustrated in figures 1, 2, and 3, yield vortices and cross currents due to obstacles, convectional swirls and ascending air columns, cyclonic storms and anticyclones and a host of other irregularities, all unsteady in the extreme.

Proceeding therefore from the fundamental hypothesis (20) one finds that, *for sufficiently long values of* $\mathfrak{T}$,

$$\bar{\bar{\alpha}}=\bar{\alpha} \quad \text{.....(21)}$$

hence by (19)

$$\bar{\alpha'}=0 \quad \text{.....(22)}$$

Moreover, if α and β represent any two of the six mass motion variables, then

$$\overline{\bar{\alpha}\bar{\beta}}=\bar{\alpha}\bar{\beta} \quad \text{.....(23)}$$

and

$$\overline{\bar{\alpha}\beta'}=0 \quad \text{.....(24)}$$

Evidently

$$\overline{\frac{\partial\alpha}{\partial t}}=\frac{\partial\bar{\alpha}}{\partial t} \quad \text{.....(25)}$$

Making use of (23) and (24), we have from (19) the relation

$$\overline{\alpha\beta}=\bar{\alpha}\bar{\beta}+\overline{\alpha'\beta'} \quad \text{.....(26)}$$

and, in particular, that

$$\left.\begin{aligned}&\overline{u^2_o}=\bar{u}^2_o+\overline{(u')^2}\\&\text{.....}\\&\text{.....}\end{aligned}\right\} \quad \text{.....(27)}$$

$$\left.\begin{aligned}&\overline{u_o v_o}=\bar{u}_o\bar{v}_o+\overline{u'v'}\\&\text{.....}\\&\text{.....}\end{aligned}\right\} \quad \text{.....(28)}$$

$$\left.\begin{aligned}&\overline{\rho u_o}=\bar{\rho}\bar{u}_o+\overline{\rho' u'}\\&\text{.....}\\&\text{.....}\end{aligned}\right\} \quad \text{.....(29)}$$

General circulation.—In what follows, the term *general circulation* will be used to denote winds of order sufficiently large to satisfy condition (20).

Derivation of the equations of general circulation.—The foregoing relations supply material from which can now be deduced the equations governing general circulation.

The dynamical equations of general circulation.—Making use of the mean value properties (19) to (29), and taking the time mean of relation (13) over an interval $\mathfrak{T}$, the equation of continuity becomes

$$\frac{\partial\bar{\rho}\bar{u}_o}{\partial x}+\frac{\partial\bar{\rho}\bar{v}_o}{\partial y}+\frac{\partial\bar{\rho}\bar{w}_o}{\partial z}=-\Phi \quad \text{.....(30)}$$

where

$$\Phi=\overline{\frac{\partial(\rho' u')}{\partial x}}+\overline{\frac{\partial(\rho' v')}{\partial y}}+\overline{\frac{\partial(\rho' w')}{\partial z}} \quad \text{.....(31)}$$

The partial time derivative $\frac{\partial\bar{\rho}}{\partial t}$ disappears by virtue of relation (20).

To derive the remaining equations is not so simple. The manner in which the density is implicated in equations (14) to (16) would complicate the analysis seriously, were it not for the fact that during any $\mathfrak{T}$-interval the density deviation ρ' from the wind density $\bar{\rho}$ is unquestionably but a small per cent of the latter. Consequently we may write

$$\frac{1}{\rho}=\frac{1}{\bar{\rho}}\left(1-\frac{\rho'}{\bar{\rho}}\right) \quad \text{.....(32)}$$

This approximation gives, with (19), the relation

$$\overline{\frac{1}{\rho}\alpha}=\frac{1}{\bar{\rho}}\bar{\alpha}-\frac{1}{\bar{\rho}^2}\overline{\rho'\alpha'} \quad \text{.....(33)}$$

[21] Rotch and Palmer (**100**, p. 44) observed, in a 33-mile wind velocity fluctuations which were between 15 and 75 miles per hour, "Including a succession of minor oscillations, some lasting only a few seconds. As many as ten pulsations in pressure per second have been noted in these rapid gusts."

[22] See equation (2).

[23] See equations (17) and (18).

[24] The apparent velocity decrease in fig. 4 of a little over 1 per cent, during the 10-year interval, was doubtless due in part to changes in exposure of the anemometer, and in part to the gradual erection of buildings near the Weather Bureau station. The instrument was located on the roof of Brown's Block from 1878 to 1883, where the exposure was probably uniform in all directions. In 1883 it was transferred to a position 71 feet distant from the dome of the Washburn Observatory, and in the lee of the dome for westerly winds. In 1904 the instrument was installed on the roof of North Hall. At that time, at least two buildings in the neighborhood of the station presented obstructions from the East and Southwest, respectively. Since then, extensive additions have been made to these buildings, and several new buildings have been erected close to the station. This progressive increase of the number and size of obstructions in the neighborhood of the anemometer appears to account for the apparent 1 per cent decrease of the velocity.

The first of equations (14) can now be thrown into the form [25]

$$\frac{du_0}{dt} = X - \frac{1}{\bar{\rho}}\frac{\partial \bar{p}}{\partial x} + \tfrac{1}{3}\epsilon \frac{\partial \bar{\theta}_0}{\partial x} + \epsilon \Delta \bar{u} + \Lambda_x + \frac{1}{\bar{\rho}^2}\Gamma_x \quad \ldots\ldots (34)$$

where

$$\Lambda_x = -\left[\overline{u'\frac{\partial u'}{\partial x}} + \overline{v'\frac{\partial u'}{\partial y}} + \overline{w'\frac{\partial u'}{\partial z}}\right] + \tfrac{1}{3}\epsilon\frac{\partial \bar{\theta}'}{\partial x} + \epsilon\Delta\bar{u}' \quad (35)$$

$$\Gamma_x = \overline{\rho'\frac{\partial p'}{\partial x}} \quad \ldots\ldots (36)$$

Similar expressions follow for $\frac{d\bar{v}_0}{dt}$ and $\frac{d\bar{w}_0}{dt}$.

The thermodynamical equations of general circulation.—Writing equation (15) in the form

$$\frac{p}{\rho} = HT$$

and using relation (32), we have for the characteristic equation of a wind

$$\bar{p} = \bar{\rho} H \bar{T} + \Xi \quad \ldots\ldots (37)$$

where

$$\Xi = \frac{1}{\bar{\rho}}\overline{\rho' p'} \quad \ldots\ldots (38)$$

The mean value theorems of general circulation (19) to (29), together with (32), when applied to (16), yield the energy equation

$$\vartheta\Delta\bar{T} + \bar{\mathfrak{G}} = \bar{\rho} c_v \frac{d\bar{T}}{dt} + \tfrac{2}{3}\rho c_v \bar{\theta}_0 + \frac{\epsilon\bar{\rho}}{J}\left[\tfrac{2}{3}\bar{\theta}_0^2 - \Sigma\left(\frac{\partial \bar{v}_0}{\partial x} + \frac{\partial \bar{u}_0}{\partial y}\right)^2 - 2\Sigma\left(\frac{\partial \bar{u}_0}{\partial x}\right)^2\right] + \frac{1}{\bar{\rho}}[\vartheta\Psi + \Pi] + \bar{\rho} c_v \Omega + \frac{\epsilon\bar{\rho}}{J}\theta \quad \ldots\ldots (39)$$

where

$$\Psi = \overline{\rho'\Delta T'} \quad \ldots\ldots (40)$$

$$\Omega = \overline{u'\frac{\partial T'}{\partial x}} + \overline{v'\frac{\partial T'}{\partial y}} + \overline{w'\frac{\partial T'}{\partial z}} \quad \ldots\ldots (41)$$

$$\theta = \tfrac{2}{3}\overline{\theta'^2} - \Sigma\left(\frac{\partial v'}{\partial x} + \frac{\partial u'}{\partial y}\right)^2 - 2\Sigma\left(\frac{\partial u'}{\partial x}\right)^2 \quad \ldots\ldots (42)$$

and

$$\Pi = \overline{\rho'\mathfrak{G}'} \quad \ldots\ldots (43)$$

[25] Notation:

$\frac{d}{dt} = \frac{\partial}{\partial t} + \bar{u}_0\frac{\partial}{\partial x} + \bar{v}_0\frac{\partial}{\partial y} + \bar{w}_0\frac{\partial}{\partial z}$, see equation (20),

$\bar{\theta}_0 = \frac{\partial \bar{u}_0}{\partial x} + \frac{\partial \bar{v}_0}{\partial y} + \frac{\partial \bar{w}_0}{\partial z}$,

$\theta' = \frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y} + \frac{\partial w'}{\partial z}$, etc.

The constants of mass motion.—Laboratory determinations have shown that, for air within the ordinary range of pressures and temperatures,

$$\begin{aligned} \kappa &= 0.000172 \\ \vartheta &= 0.000056 \\ c_v &= 0.169 \\ J &= 4.18\times 10^7 \\ \epsilon &= 0.133 \end{aligned} \quad \ldots\ldots (44)[26]$$

These determinations have been carried out for nonturbulent stream-line configurations, which should be expected to indicate the true mass motion, and not time averages of the mass motion. The substantial agreement of results obtained by different methods for a variety of apparently nonturbulent motions,[27] and the extreme divergence of results where turbulence of any order has been observed,[28] seem to establish beyond a reasonable doubt that, within ordinary ranges of pressure and temperature, (*a*) the above values pertain to the mass motion proper, and (*b*) that they are practically invariant for a given gas with respect to all mass motions experimentally investigated. According to the Kinetic Theory of Gases, they should be practically invariant with respect to all possible mass motions.

Approximations applicable to general circulation.—For sufficiently large values of $\mathfrak{T}$, it is probable that the space derivatives of the wind velocities are small. Since ϵ and ϑ are also small, and $\frac{\epsilon}{J}$ is very small indeed, the dilitation and divergence terms of the momentum equations are probably negligible compared with the gradient forces $\left(-\frac{1}{\rho}\frac{\partial p}{\partial x}\right)$, etc., and also the conduction and dissipation terms of the energy equation, compared with the terms expressing the time rates of change of internal and dilitation energy.

The equations of general circulation.—Equations (30) to (39), therefore, after subscripts and bars have been removed, assume the approximate form:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = -\Phi \quad \ldots\ldots (45)$$

$$\frac{du}{dt} = X - \frac{1}{\rho}\frac{\partial p}{\partial x} + \Lambda_x + \frac{1}{\rho^2}\Gamma_x \quad \ldots\ldots (46)$$

$$\frac{dv}{dt} = Y - \frac{1}{\rho}\frac{\partial p}{\partial y} + \Lambda_y + \frac{1}{\rho^2}\Gamma_y \quad \ldots\ldots (47)$$

$$\frac{dw}{dt} = Z - \frac{1}{\rho}\frac{\partial p}{\partial z} + \Lambda_z + \frac{1}{\rho^2}\Gamma_z \quad \ldots\ldots (48)$$

$$p = \rho H T + \Xi \quad \ldots\ldots (49)$$

$$\rho c_v \frac{dT}{dt} + \tfrac{2}{3}\rho c_v \theta - \mathfrak{G} = -\left\{\frac{1}{\rho}(\vartheta\Psi + \Pi) + \rho c_v \Omega + \frac{\epsilon\rho}{J}\theta\right\} \quad \ldots\ldots (50)$$

[26] *C. G. S* units; gram-calories.
[27] See, for example, the viscosity determinations: **62, 63, 64, 65, 66, 67, 68, 69, 96.**
[28] **70, 71, 72, 6, 12.**

The turbulence functions.—The functions Λ and $\frac{1}{\rho^2}\Gamma$ are evidently tractions due to transfers of momentum within the air, which impede or accelerate the wind. It will be observed that $\frac{1}{\rho^2}\Gamma$ depends directly upon the wind density and on the density and pressure deviations, while Λ depends directly upon the velocity deviations alone. Λ therefore is of the nature of a *kinetic traction*, and $\frac{1}{\rho^2}\Gamma$, of a *thermodynamic traction*. It is reasonable to suppose that these two forces which, though mutually dependent differ essentially, correspond more or less closely to the observed distinction between kinetic and convective turbulence, in which case the distinction would prove to be fundamental.

The function Φ shows that the wind motion is not in general a possible mode of mass motion; that is to say, observed wind motions may show *apparent* deviations from the law of conservation of matter; such deviations are measured by Φ.

The apparent elastic behavior of a wind may also be expected to deviate from that of a perfect gas under laboratory conditions (i. e., in nonturbulent motion). In this case, the deviation is measured by the function Ξ.

Finally, Ψ, Ω, Π and θ measure the energy transfer due to kinetic and convective turbulence in the wind.

It can not be emphasized too strongly that these functions, corresponding to a given mass motion, will in general vary greatly from one value of $\mathfrak{T}$ to another. The tractions accompanying the wind represented by figure 1, for example, unquestionably differ profoundly in character and magnitude from those accompanying the wind represented by figure 4.

Empirical determination of the turbulence functions.—As should be expected from the nature of air resistances, these turbulence functions are complex in the extreme. To attempt to ascertain wind motion deviations and deviation rates, and to find mean values of their powers and products, would not be profitable, nor is it necessary. The problem here is precisely analogous to the problem of kinetic friction between rigid bodies, which latter is a traction due to the interaction of molecules in the bearing surfaces. That kinetic friction has been successfully reckoned with and usefully applied is due to the fact that empirical formulas have been invented, making it unnecessary to ascertain the detailed motion of the molecules. To investigate the turbulence functions of the general circulation by empirical methods is therefore an immediate and fundamental problem.

The principle stated at the end of the last section finds explicit application here. The order of the wind under consideration will determine the forms to be assigned empirically to the turbulence functions, as well as the values of such numerical coefficients as they may contain. Turbulence laws governing a wind around an aëroplane strut and defined for ten-second means, would doubtless have little in common with turbulence laws governing a general circulation of the atmosphere defined for $\mathfrak{T}$-intervals of thirty years.

Geographical coordinates.—For the purpose of investigating the turbulence functions of general circulation, it is advantageous to transform the equations of motion by replacing the fixed, rectangular coordinate system which we have been using by a system of geographical coordinates moving with the earth. Assuming rectangular axes fixed instantaneously at point P as in figure 5, then

$$u=r\cos\theta\cdot(\dot{\varphi}+\varpi),\ v=r\,\dot{\theta},\ w=\dot{r}\quad\ldots\ldots\ldots(51)^{39}$$

where θ is the North latitude of P, φ is its East longitude, and r, its distance from the earth's center. The dots denote time rates. If E is the eastward component of the relative wind velocity at P, and N and V, the respective northward and vertical components, then

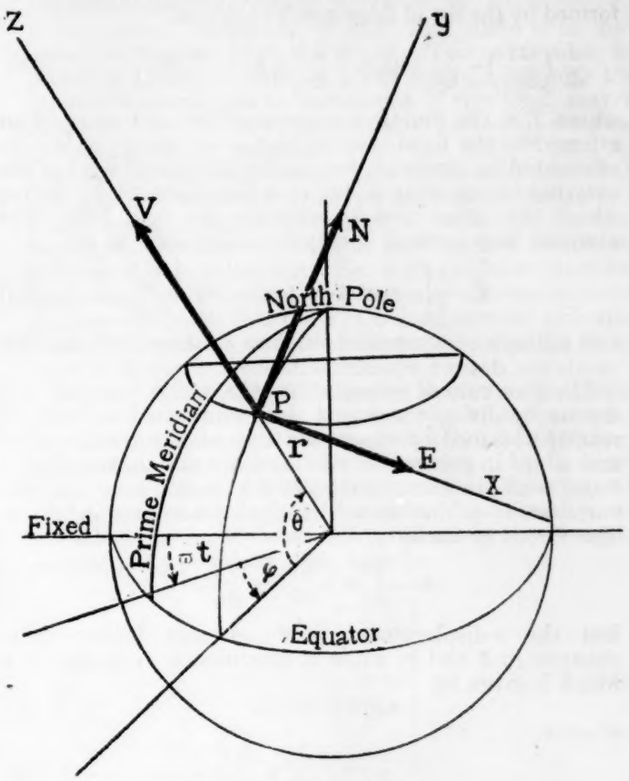


FIG. 5.—Geographical coordinates.

$$E=r\cos\theta\cdot\dot{\varphi},\ N=r\,\dot{\theta},\ V=\dot{r}\quad\ldots\ldots\ldots(52)$$

Since the left-hand member of (45), if equated to zero, gives the equation of continuity for the detailed motion (not the average motion) of a continuous medium, the transformation of the equation of continuity is readily effected by computing the flux of such a medium into a geographical volume element. The eastward flux is

$$-\frac{1}{r\cos\theta}\frac{\partial(\rho E)}{\partial\varphi}d\tau dt,$$

the northward flux is

$$-\frac{1}{r}\frac{\partial(\rho N)}{\partial\theta}d\tau dt$$

and the upward flux is

$$-\frac{\partial(\rho V)}{\partial r}d\tau dt.$$

[39] The number ϖ is the angular velocity of the earth's rotation: 0.00007292 radians per second.

The total net flux, however, would be

$$\frac{\partial \rho}{\partial t} d\tau dt;$$

consequently, the first term, plus the last three with signs reversed, give the desired function.

The momentum equations are expeditionsly transformed by the use of Lagrange's equations [30]

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)-\frac{\partial T}{\partial q_i}=Q_i-\frac{1}{\rho}\frac{\partial p}{\partial q_i}+\Lambda_i+\frac{1}{\rho^2}\Gamma_i \quad \text{.....(53)}$$

where T is the kinetic wind energy per unit mass of air referred to the fixed, rectangular axes, and Q_i is the coefficient of δq_i in the expression for the virtual work of the external forces, that is due to a displacement δq_i during which the other two coordinates are held fast. The absolute kinetic wind energy is readily seen to be

$$T=\frac{1}{2}\left\{r^2\cos^2\theta\cdot(\varphi+\varpi)^2+r^2\dot{\theta}^2+\dot{r}^2\right\} \quad \text{.....(54)}$$

and a simple computation based on relations (51) and (54) yields the desired equations.

The time rate of cubical dilitation, which we shall now denote by div q, where q is the vector wind velocity, is readily obtained by observing that, at any instant, u, v, and w are in general functions of r, θ and φ, and that r, θ and φ are, in turn, functions of x, y, and z, so that the variation in u due to a virtual displacement in the x-direction is given by

$$\delta u=\frac{\partial u}{\partial r}\delta r+\frac{\partial u}{\partial \theta}\delta\theta+\frac{\partial u}{\partial \varphi}\delta\varphi.$$

But the x-displacement produces only higher order changes in θ and r, while it produces a variation in φ which is given by

$$r\cos\theta\cdot\delta\varphi=\delta x;$$

whence

$$\frac{\partial u}{\partial x}=\frac{1}{r\cos\theta}\frac{\partial E}{\partial \varphi} \quad \text{.....(55)}$$

The partial derivatives of v and w are computed in a similar manner; consequently

$$\operatorname{div} q=\frac{1}{r\cos\theta}\frac{\partial E}{\partial \varphi}+\frac{1}{r}\frac{\partial N}{\partial \theta}+\frac{\partial V}{\partial r} \quad \text{.....(56)}$$

The equations of general circulation in geographical coordinates.—The above equations may now be written as follows[31]:

$$\frac{1}{r\cos\theta}\frac{\partial(\rho E)}{\partial \varphi}+\frac{1}{r}\frac{\partial(\rho N)}{\partial \theta}+\frac{\partial(\rho V)}{\partial r}=-\Phi \quad \text{.....(57)}$$

$$\frac{dE}{dt}=\left\{\frac{EN}{r}\tan\theta-\frac{VE}{r}\right\}+\left[2\varpi N\sin\theta-2\varpi V\cos\theta\right]$$
$$-\frac{1}{r\cos\theta}\left(\frac{1}{\rho}\frac{\partial p}{\partial \varphi}\right)+\Lambda_E+\frac{1}{\rho^2}\Gamma_E \quad \text{.....(58)}$$

$$\frac{dN}{dt}=\left\{-\frac{E^2}{r}\tan\theta-\frac{NV}{r}\right\}+\left[-2\varpi E\sin\theta\right]$$
$$-\frac{1}{r}\left(\frac{1}{\rho}\frac{\partial p}{\partial \theta}\right)+\Lambda_N+\frac{1}{\rho^2}\Gamma_N \quad \text{.....(59)}$$

$$\frac{dV}{dt}=\left\{\frac{E^2+N^2}{r}\right\}+\left[2\varpi E\cos\theta\right]-g-\frac{1}{\rho}\frac{\partial p}{\partial r}+\Lambda_V+\frac{1}{\rho^2}\Gamma_V \quad \text{.....(60)}$$

$$p=\rho HT+\Xi \quad \text{.....(61)}$$

$$\rho c_v\frac{dT}{dt}+\tfrac{2}{3}\rho c_v\left\{\frac{1}{r\cos\theta}\frac{\partial E}{\partial \varphi}+\frac{1}{r}\frac{\partial N}{\partial \theta}+\frac{\partial V}{\partial r}\right\}-\mathfrak{G}$$
$$=-\left\{\frac{1}{\rho}\left(\vartheta\Psi+\Pi\right)+\rho c_v\Omega+\frac{\epsilon\rho}{J}\theta\right\} \quad \text{.....(62)}$$

The quadratic terms in E, N, and V occurring in the momentum equations are negligible compared with the accelerations of Coriolis,[32] provided that $\frac{E}{r}$, $\frac{N}{r}$, and $\frac{V}{r}$ are small compared with ϖ.

Viscous fluid analogies.—The classical analysis of internal stresses set up by the motion of an isotropic, homogeneous, continuous medium within the medium itself furnishes an advantageous starting point for an empirical investigation of the turbulence functions of general circulation, to which we now return. The momentum equations for a thin layer of any continuous medium enveloping the earth may be written as follows:[33]

$$\left.\begin{aligned}
J_E&=-\frac{1}{r\cos\theta}\left(\frac{1}{\rho}\frac{\partial p}{\partial \varphi}\right)+\frac{1}{\rho}\left\{\frac{1}{r\cos\theta}\frac{\partial E_e}{\partial \varphi}+\frac{1}{r}\frac{\partial E_n}{\partial \theta}+\frac{\partial E_v}{\partial r}\right\}\\
J_N&=-\frac{1}{r}=\left(\frac{1}{\rho}\frac{\partial p}{\partial \theta}\right)+\frac{1}{\rho}\left\{\frac{1}{r\cos\theta}\frac{\partial N_e}{\partial \varphi}+\frac{1}{r}\frac{\partial N_n}{\partial \theta}+\frac{\partial N_v}{\partial r}\right\}\\
J_V&=-g-\frac{1}{\rho}\frac{\partial p}{\partial r}+\frac{1}{\rho}\left\{\frac{1}{r\cos\theta}\frac{\partial V_e}{\partial \varphi}+\frac{1}{r}\frac{\partial V_n}{\partial \theta}+\frac{\partial V_v}{\partial r}\right\}
\end{aligned}\right\} \quad (63)$$

where J is the resultant of the relative acceleration, the small accelerations discussed in the last paragraph, and the accelerations of Coriolis. If the medium is homogenous and isotropic, and if the velocities and their space derivatives are so small that their squares and products may be neglected,[34] then the tensions or compressions per unit area within the fluid are

$$\left.\begin{aligned}
E_e&=\lambda\operatorname{div} q+\frac{2\mu}{r\cos\theta}\frac{\partial E}{\partial \varphi}\\
N_n&=\lambda\operatorname{div} q+\frac{2\mu}{r}\frac{\partial N}{\partial \theta}\\
V_v&=\lambda\operatorname{div} q+2\mu\frac{\partial V}{\partial r}
\end{aligned}\right\} \quad \text{.....(64)}$$

and the shearing stresses per unit area within the fluid are

$$\left.\begin{aligned}
E_n=N_e&=\mu\left\{\frac{1}{r\cos\theta}\frac{\partial N}{\partial \varphi}+\frac{1}{r}\frac{\partial E}{\partial \theta}\right\}\\
N_v=V_n&=\mu\left\{\frac{1}{r}\frac{\partial V}{\partial \theta}+\frac{\partial N}{\partial r}\right\}\\
V_e=E_v&=\mu\left\{\frac{\partial E}{\partial r}+\frac{1}{r\cos\theta}\frac{\partial V}{\partial \varphi}\right\}
\end{aligned}\right\} \quad \text{.....(65)}$$

[30] 73, p. 343. In equations (53), $i=(1, 2, 3)$, and $q_1=r$, $q_2=\theta$ and $q_3=\varphi$.

[31] $\frac{d}{dt}=\frac{E}{r\cos\theta}\frac{\partial}{\partial \varphi}+\frac{N}{r}\frac{\partial}{\partial \theta}+V\frac{\partial}{\partial r}$ .....(56a)

When this operator is applied to E, N, or V, the result will be referred to as a relative acceleration. The absence of the partial time derivatives is due to the hypothesis expressed by equation (20), and to the definition of general circulation.

[32] The terms inclosed in square brackets. See 74.

[33] E_e, etc., are the internal stresses due to the viscosity of the medium. Each stress lies in a plane perpendicular to the direction denoted by the subscript, and the direction of the stress is denoted by the capital letter. The depth of the medium is assumed to be small compared with the radius of the earth.

The equations for the motion of a viscid, continuous medium in their classical form were first suggested by Navier (75) and subsequently derived by Saint-Venant (76) and Stokes (52 and 77). See also (29) and (78).

[34] See (73, p. 554). The numbers λ and μ are the viscosity coefficients for the medium. If $3\lambda+2\mu=0$, then the medium is such that uniform dilitation without shearing can take place without dissipation of energy. There seems to be no good reason for supposing this relation to hold for viscous media in general; see (76, p. 1240); (52, p. 287); (77, p. 16); (80, p. 95); (81, p. 174); (78, Vol. 1, p. 22); (82, p. 462). But the relation probably is true for gases; see (79, p. 116, 193).

From the standpoint of the Kinetic Theory of Gases, all of these stresses and hence the resulting tractions are due to molecular transfers of momentum in the medium. In the preceding analysis, we have seen that the *wind* tractions Λ and $\frac{1}{\rho^2}\Gamma$ are due to turbulent transfers of momentum in the wind itself. But winds are anisotropic, at least to transfers effected by convective turbulence, and the velocities and their space derivatives are by no manner of means so small that their squares and products can be neglected. Equations (64) and (65) therefore can not possibly represent the internal mechanism of a wind in a state of convective turbulence.

On the other hand, if a viscous fluid were anisotropic, but (*a*) the tensions or compressions due to the fluid motion were proportional to the differential velocities, and (*b*) the shearing stresses obeyed a similar law and acted only in horizontal planes, then relations (64) and (65) would read

$$\left.\begin{aligned} E_e &= \frac{2\mu}{r\cos\theta}\frac{\partial E}{\partial \varphi} \\ N_n &= \frac{2\mu}{r}\frac{\partial N}{\partial \theta} \\ V_v &= 2\mu\frac{\partial V}{\partial r} \end{aligned}\right\} \qquad (66)$$

$$\left.\begin{aligned} &E_n = N_e = V_e = V_n = O \\ &N_v = \mu\frac{\partial N}{\partial r} \\ &E_v = \mu\frac{\partial E}{\partial r} \end{aligned}\right\} \qquad (67)$$

Equations (63) show that the corresponding eastward traction would be

$$\epsilon\left\{\frac{2}{r^2\cos^2\theta}\frac{\partial^2 E}{\partial\varphi^2}+\frac{\partial^2 E}{\partial r^2}\right.$$

the northward traction would be

$$\epsilon\left\{\frac{2}{r^2}\frac{\partial^2 N}{\partial\theta^2}+\frac{\partial^2 N}{\partial r^2}\right\}$$

and the vertical traction would be

$$\epsilon\left\{2\frac{\partial^2 V}{\partial r^2}\right\}$$

where $\epsilon=\frac{\mu}{\rho}$, which is practically constant.

Finally, if the condition be imposed that the pressures are small compared with the shearing stresses, it is evident from (63) that the eastward traction becomes

$$\left.\begin{aligned} &\epsilon\frac{\partial^2 E}{\partial r^2}, \\ &\text{the northward traction,} \\ &\epsilon\frac{\partial^2 N}{\partial r^2} \\ &\text{and the vertical traction,} \\ &O. \end{aligned}\right\} \qquad (69)$$

Consideration of the motion [35] defined by the relations

$$E=ar,\ N=br,\ V=O,\ \rho=\text{const.}$$

will show that a medium satisfying conditions (69) is vertically isotropic to momentum transfers producing the horizontal tangential resistances (67).

The analogy of these systems of resistances may serve as an advantageous starting point for the study of wind tractions. Since the character of these tractions depends fundamentally on the $\mathfrak{T}$-interval, we shall accordingly assume, for the sake of definiteness, that the averages are computed over intervals of thirty years.

For general circulation of this order there is no good reason to suppose that the winds are anisotropic to the action of *kinetic* turbulence. The analogy suggests that internal stresses, due to turbulence of this kind, may be linear functions of the differential velocities in the manner indicated by relations (64) and (65);[36] in which case Λ_E, for example, would be a linear function of the divergence of the wind velocity q and the Laplacian of E. Such a law might reasonably be expected to hold for winds having differential velocities as high as 0.01 centimeter per second per centimeter. For higher differential velocities it might be necessary to express the stresses as homogeneous quadratic functions of the differential velocities. Higher differential velocities, however, probably do not occur in general circulation.

Convective turbulence evidently obeys a very different law. While winds may be isotropic to the action of kinetic turbulence, they are certainly anisotropic to momentum transfers due to convection. In fact, convective turbulence for the most part must act vertically across horizontal surface elements. The simplest and probably the most plausible hypothesis is therefore that suggested by relations (69), namely,

$$\left.\begin{aligned} \Gamma_E &= \frac{\mu}{\rho^2}\frac{\partial^2 E}{\partial r^2} \\ \Gamma_N &= \frac{\mu}{\rho^2}\frac{\partial^2 N}{\partial r^2} \\ \Gamma_V &= O \end{aligned}\right\} \qquad (70)$$

where μ is a constant depending on $\mathfrak{T}$.

The functions Ψ, Ω, Π, and θ present very much the same problem as the tractions. On account of the extreme smallness of the coefficient of θ, it is probable that kinetic turbulence can here be neglected. As to the relative values of the terms in Ψ, Ω, and Π, nothing at present can be said. A practicable working hypothesis is suggested by the analogy of Fourier's law of

[35] This motion satisfies the equation of continuity. The stream lines are

$$b\varphi=\varpi\theta+a\log\beta\,(\tan\theta+\sec\theta)$$

where β is a parameter varying from one curve to another.

[36] *The dynamical significance of the barometer.*—If governed by the laws expressed by (64), the total normal internal pressure per unit area would be

$$\left.\begin{aligned} P_e &= -p+E_e \\ P_n &= -p+N_n \\ P_v &= -p+V_v \end{aligned}\right\} \qquad (69a).$$

These relations throw some light on the dynamical significance of the barometer. Let us imagine an ideal shelter constructed on the principles of a lantern, allowing indirect contact between the exterior and interior air, but excluding the wind. The dimensions of this ideal shelter are microscopic and of the same order as those of the cell dr, in which we shall suppose it to be placed. This shelter, which is stationary, obstructs the wind, thus setting up extraneous disturbances, influencing to an unknown extent the behavior of the instruments inside. One of the latter, an ideal, microscopic barometer registering the most rapid and minute pressure fluctuations, would, however, indicate the aërostatic pressure p in the *shelter*, for the shelter would evidently eliminate the aërodynamic pressures E_e, N_n and V_v. Assuming that the turbulence set up by the shelter on its exterior, together with the destruction of the mass motion in its interior, does not result in totally transforming the character of the molecular motion normally occurring in the geometrical *cell* dr, the ideal instrument would yield an approximate value for the pressure p of the classical Kinetic Theory of Gases, as defined by equation (11). Time averages of successive readings made at sufficiently near intervals would therefore give the aërostatic wind pressure $\bar{p}$ as defined by equation (17).

In the actual case the analogon of the microscopic shelter is the closed room in which the standard barometer is suspended. The latter does not respond to rapid and minute pressure fluctuations (2), and consequently it yields at a single reading an approximate time mean corresponding to an indeterminate time interval. When, however, successive readings of the standard instrument under standard conditions are averaged over a fixed and definite interval $\mathfrak{T}$, the resulting means apparently afford a more or less rough approximation to the true aërostatic pressure $\bar{p}$ of the wind. (See equation (17)). How nearly this approximation represents the true value is a question which would well repay experimental investigation.

heat conduction in a continuous, homogeneous medium, namely, that convective energy transfer through a thin wind stratum is directly proportional to the temperature difference of its boundaries and to the time, and inversely proportional to the thickness of the stratum. If to this is added the assumption that transfers occur in the vertical direction only, the corresponding turbulence function will be proportional to

$$\frac{1}{\rho}\frac{\partial^2 T}{\partial r^2} \qquad (71)$$

or else to

$$\rho\frac{\partial^2 T}{\partial r^2} \qquad (72)$$

The functions Φ and Ξ occurring respectively in the equation of continuity and in the characteristic equation are at present entirely problematic, but it is probable that, as the anology of viscous motion suggests, these functions may play an unimportant rôle.

Studies of resistance functions.—The science of the internal mechanism of winds is a new one. It opens a wide field for research, the results of which can not fail to prove of the utmost interest and utility. Attempts have already been made to devise resistance functions and to evaluate the corresponding constants. All of these attempts have been made under the assumption of a general air drift differing from the detailed fluid motion; but in no case has the exact nature of the drift under consideration been defined, nor has the all-important question of wind order been investigated.

Guldberg and Mohn [37] assumed that the internal resistance F per unit mass of air was proportional to W, the horizontal wind velocity:

$$\left.\begin{aligned} F &= \mu W \\ W &= \sqrt{E^2+N^2} \end{aligned}\right\} \qquad (73)$$

and that the resistance acted directly against the wind. Neglecting relative accelerations and the small quadratic terms in E, N, and V, the two hydrodynamical equations corresponding to (58) and (59) yield the relation

$$\frac{1}{\rho}\frac{\partial p}{\partial s} = 2\varpi\, W\sin\theta - F_s$$

where s is the direction in which the pressure gradient is steepest. Since the "deflective force" $2\varpi W\sin\theta$ acts normal to the path and, in the Northern Hemisphere, to the right, it follows that [38]

$$\left.\begin{aligned} -\frac{1}{\rho}\frac{\partial p}{\partial s}\cos\alpha &= \mu W \\ -\frac{1}{\rho}\frac{\partial p}{\partial s}\sin\alpha &= 2\varpi W\sin\theta \end{aligned}\right\} \qquad (74)$$

Consequently

$$\mu = (2\varpi\sin\theta)\operatorname{cotan}\alpha.$$

Values of the deflection angle obtained from weather maps gave

$$0.0002 > \mu > 0.00008.$$

To check the resistance law on which these results depended, advantage was taken of the fact that sufficient data were at hand to over-determine equations (74). The ratio of W to $\frac{\partial p}{\partial s}$ was computed from previously obtained values of μ, and, as was to have been expected from the nature of the resistance function, the results did not check well with observations.

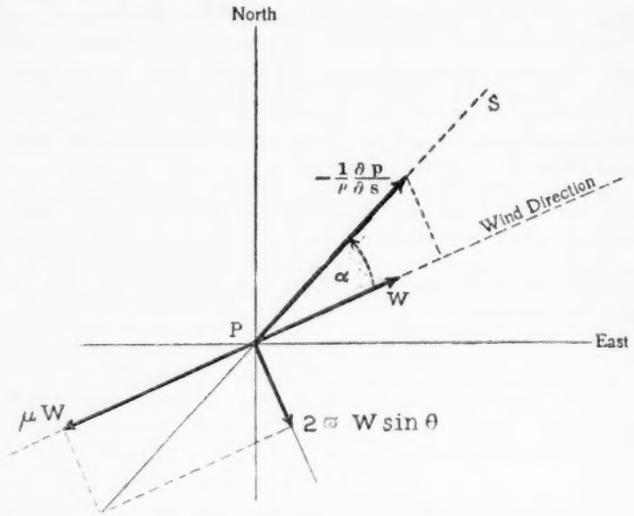


FIG. 6.—Guldberg and Mohn deflection angle, α. The direction s is that in which the gradient force is at a maximum.

Oberbeck [39] assumed that resistances obeyed the law

$$F = \frac{\mu}{\rho}\Delta q,$$

where μ was a constant depending on the motion.

Åkerblom,[40] in his researches relating to the winds over Paris, assumed that

$$F_E = \frac{\mu}{\rho}\frac{\partial^2 E}{\partial r^2}, \quad F_N = \frac{\mu}{\rho}\frac{\partial^2 N}{\partial r^2}$$

where, as with Oberbeck, μ was a constant depending on the internal irregularities of the average drift. Neglecting accelerations, and imposing restrictions on the velocities, he found that

$$\mu = 95\frac{\text{gm.}}{\text{cm. sec.}}.$$

Hesselberg and Sverdrop [41] assumed that

$$F = \kappa\frac{W_{500}-W_0}{500} - k\,W_0.$$

The first term was introduced under the supposed necessity of representing separately the traction of the upper layers upon the lower ones. The second term was intended to represent the tractions at the ground. The difference quotient

$$\frac{W_{500}-W_0}{500}$$

was evidently a rough approximation not to $\frac{\partial^2 W}{\partial r^2}$ but to $\frac{\partial W}{\partial r}$, and as here used was equivalent to the assumption of horziontal shearing stresses in the upper air which are proportional not to the differential velocities but to the velocities themselves. It is difficult to see how such a

[37] (70. See also 83.) Stokes pointed out in 1845 that "The main part of the resistance of fluids depends on the formation of eddies." 53, p. 99.
[38] See fig. 6. The angle α was called the *deflection angle*.
[39] 84. See also the memoirs of Boussinesq, 85 and 86.
[40] 71. See also 87.
[41] 72. See also 88.

law could prove valid. Possibly with this in mind, Hesselberg and Sverdrop carried out another determination depending on the law already suggested by Åkerblom. In this case the second derivatives were obtained from observations.

A study of a very restricted type of eddy motion superimposed upon a horizontal air drift led Taylor [42] to adopt for horizontal tractions the law assumed by Åkerblom. Similar considerations led to the assumption of a law to the effect that the transfer of heat by turbulent motion is proportional to

$$\frac{\partial^2\theta}{\partial z^2},$$

where θ is the potential temperature of the air at altitude z. This law would necessitate either a horizontal downward transfer of energy by turbulence in the isothermal region, where the potential temperature increases with altitude, or else it would necessitate a strong variation with altitude of the proportionality factor. Since observations indicate distinctly a state of nonturbulence in the isothermal region,[43] the former alternative is untenable. The latter alternative imposes upon the proportionality factor the burden of an entirely unknown function, and therefore yields no additional information as to the general circulation.

These various studies seem to be significant for the problem of general circulation (*a*) in that they contain proposed resistance laws which may prove useful as working hypotheses, and (*b*) in that they illustrate the importance of a fundamental principle which, curiously enough, seems to have been entirely overlooked except by Guldberg and Mohn, namely, that empirical determinations of resistance constants are meaningless unless sufficient data are brought to bear to over-determine the equations of motion, and so *to verify the empirical resistance laws on which the results depend.* It should be added that empirically determined results should be expected to hold only for *definite vaules of* $\mathfrak{T}$ *corresponding to the order of the winds under investigation.*

REFERENCES.

1. **Langley.** Phil. Mag. 1894, **37.**
2. **Barkow.** Met. Zeit., 1915.
3. **Becker.** Ann. der Physik, 1907, **24.**
4. **Dowling.** Dublin R. S. Proc., 1912.
5. **Ekman.** Arkiv. für Mat., Astron. och Fys., 1909, **6,** 12.
6. **Emden.** Wied. Ann. 1899, **69.**
7. **Fry and Tyndall.** Phil. Mag. 1911, **21.**
8. **Hahn, Herglotz u. Schwarzschild.** Zs. f. Math. u. Phys., 1904, **51.**
9. **Holm.** Ann. der Physik, 1914, **44.**
10. **King.** Journ. Franklin Inst., Jan., 1916.
11. **Knudsen.** Ann. der Physik, 1909, **28.**
12. **Kohlrausch.** Ann. der Physik, 1914. **44.**
13. **Lorentz.** Abhandlungen über Theoretische Physik, Leipzig u. Berlin, 1907.
14. **Mach, E. u. Salcher.** Wien. Ber., 1889, (2) **98.**
15. **Mach, L.** Wien. Ber. 1897, **106.**
16. **Oseen.** Ark. for Math., Astron. och Fys., **3,** 20, 24; **4,** 9.
17. **Parentz.** Ann. de Chim. et Phys., 1897, (7) **12.**
18. **Poisuille.** Compt. Rend., 1843, **15.**
19. **Reynolds.** Lond. Phil. Trans., 1883.
20. **Reynolds.** Roy. Inst. of Great Brit. Proc., 1884.
21. **Reynolds.** Roy. Inst. of Great Brit. Proc., 1893.
22. **Reynolds.** Lond. Phil. Trans., 1895.
23. **Schaefer u. Frankenberg.** Physik. Zs., 1913, **14.**
24. **Sharpe.** Amer. Math. Soc. Trans., 1905, **6.**
25. **Zemplén.** Ann. der Physik, 1912, **38.**
26. **Neru.** Beibl. 1912, **36.**
27. **Ahlborn.** Ueber den Mechanismus des Hyd.Widers. Hamburg,1902.
28. **Brillouin.** Toulouse Ann., 1887.
29. **Brillouin.** Leçons sur la Viscosite des Liquids et des Gas, Paris, 1907.
30. **Brillouin.** Compt. Rend., 1910, **151.**
31. **Brillouin.** Compt. Rend., 1911, **153.**
32. **Brillouin.** Ann. de Chim. et Phis., 1911, (8) **22.**
33. **Brillouin.** Ann. de Chim. et Phis., 1911, (8) **23.**
34. **Dines.** Aëronautical Journ., 1911.
35. **Duchêne.** Mechanics of the Aëroplane, translated by Ledeboer and Hubbard, New York, 1912.
36. **Eiffel.** Resistance of the Air, translated by Hunsaker. Boston, 1913
37. **Greenhill.** The Dynamics of Mechanical Flight, London, 1912.
38. **Love.** Camb. Phil. Soc. Proc., 1891, **7.**
39. **Helmholtz.** Phil. Mag., 1868, **36.**
40. **Helmholtz.** Berl. Ber., 1888, translated by Abbe, Smithson. Misc. Coll. **34.**
41. **Helmholtz.** Berl. Ber., 1889, translated by Abbe, Smithson Misc. Coll. **34.**
42. **Helmholtz.** Berl. Ber., 1890, translated by Abbe, Smithson. Misc. Coll., **34.**
43. **Helmholtz.** Wissensch. Abh. Leipzig, 1882, **1.**
44. **Hoernes.** Buch der Fluges, Vienna, 1911, **2.**
45. **Kelvin.** Nature, 1894, **50** (pages 524, 549, 573, 597).
46. **Kirchhoff.** Crelle, 1869, **70.**
47. **Lanchester.** Aërodynamics, New York, 1908.
48. **Marey.** Compt. Rend., 1893.
49. **Levi-Civita.** Palermo Rend., 1907, **23.**
50. **Rayleigh.** Phil. Mag.,1876, (5) **2.**
51. **Shaw.** Aëronautical Journ., July, 1914.
52. **Stokes.** Camb. Phil. Trans., 1847, **8.**
53. **Stokes.** Collected Papers, Cambridge, 1880, **1.**
54. **Villat.** Annals Sci. de l'Ecole Normale Superieure, 1911, (3) **28.**
55. **Kirchhoff.** Mechanik, Leipzig, 1877, Vorles, **21, 22.**
56. **Dietzius.** Beitr. z. Phys. d. fr. Atmos., 1914.
57. **von Hergesell.** Beitr. z. Phys. d. fr. Atmos., 1914.
58. **Schmauss.** Beitr. z. Phys. d. fr. Atmos., 1914, **6.**
59. **Schmauss.** Beitr. z. Phys. d. fr. Atmos., 1914, **7.**
60. **Wegener.** Met. Zeit., 1912, **29.**
61. **Lilienthal.** Birdflight, translated by Isenthal, London, 1911.
62. **Meyer, O. E.** Pogg. Ann., 1863, **125.**
63. **Meyer, O. E.** Pogg. Ann., 1866, **127.**
64. **Meyer, O. E.** Pogg. Ann., 1871, **142.**
65. **Meyer, O. E.** Pogg. Ann., 1871, **143.**
66. **Meyer, O. E.** Pogg. Ann., 1873, **148.**
67. **Maxwell.** Lond. Phil. Trans., 1866, **156.**
68. **Kundt u. Warburg.** Pogg. Ann., 1875, **155.**
69. **Zemplén.** Drude's Ann., 1906, **19.**
70. **Guldberg et Mohn.** Études sur le Mouvement de l'Atmosphère, Christina, 1876 et 1880 (two papers). Translated by Abbe, Smithson. Misc. Coll., **51.**
71. **Åkerblom.** Nova Acta Reg. Soc. Si. Upsala, 1908.
72. **Hesselberg.** Met. Zeit., 1914.
73. **Appell.** Méchanique Rationelle, Paris, 1909, **3.**
74. **Coriolis.** Journ. de l'École Polytech., 1835, Tome **15,** Cah. 24, p. 142.
75. **Navier.** Mem. de l'Acad., 1822, **6.**
76. **Saint-Venant.** Compt. Rend.,1843, **17.**
77. **Stokes.** Cambr. Phil. Soc. Proc., 1845.
78. **Duhem.** Recherches sur l'Hydrodynamique, Paris, 1903.
79. **Kirchhoff.** Theorie der Wärme, Leipzig, 1894 (pages 116, 193).
80. **Natanson.** Bull. de l'Acad. des Sci. de Cracovie, 1901.
81. **Poisson.** Journ. de l'École Polytech., 1831, Tome **13,** Cah. 20.
82. **Voigt.** Theoretische Physik, Leipzig, 1895, Bd. **1.**
83. **Gordenski.** Met. Zeit., 1907.
84. **Oberbeck.** Berl. Ber., 1888 (pp. 383–395 and 1129–1138). Translated by Abbe, Smithson. Misc. Coll., **34.**
85. **Boussinesq.** Mem. des Savantes Étrangers, 1877, **23,** 1.
86. **Boussinesq.** Théorie de l'Ecoulement Turbillont et Tumulteaux des Liquides, Paris, 1897.
87. **Sharpe.** Amer. Journ. of Math., 1910, **32.**
88. **Sandström.** Mount Wea. Obs. Bull., 1911.
89. **Riabouchinsky.** Spectres Aerodynamique, Bull. de l'Inst. Koutchino.
90. **Blair.** Monthly Wea. Rev., April, 1916.
91. **Maxwell.** Lond. Phil. Trans., 1867, **157.**
92. **Kelvin.** Math. and Phys. Papers, Cambridge, 1882, **1.**
93. **Rayleigh.** Phil. Mag., 1913, (6) **26.**
94. **Taylor.** Lond. Phil. Trans., 1915, **215.**
95. **Taylor.** Lond. Roy. Soc. Proc., 1916, **92.**
96. **Vogel.** Ann. der Physik, 1914.
97. **Exner u. Trabert.** Encyclopädie der Math. Wissenschaften, Bd. **VI,** Hft. 3.
98. **Greenhill.** Report 19, Advisory Committee for Aëronautics, London, 1910.
99. **Taylor.** Lond. Roy. Soc. Proc., 1918, **94.**
100. **Rotch and Palmer.** Charts of the Atmosphere for Aëronauts and Aviators, New York, 1911.
101. **Wegener.** Thermodynamik der Atmosphäre, Leipzig, 1911.
102. **Hellmann.** Met. Zeit., 1915, **32,** p. 1.
103. **Lees.** Lond. Roy. Soc. Proc., 1914, **91,** p. 46.
104. **Bryan and Jones.** Lond. Roy. Soc. Proc., 1915, **91,** p. 354.

[42] 94, 95, 99. [43] Above the substratosphere. See 58 and 59.

INFLUENCE OF FORESTS UPON THE MELTING OF SNOW IN THE CASCADE RANGE.

Compiled by ALFRED A. GRIFFIN, Forest Examiner.

[Dated: Portland, Oreg., April, 1918.]

The melting of snow in the forest and in the open has been the subject of much study, but without the accumulation, in America at least, of any large amount of data on the subject. Jaenicke and Foerster[1] found that a yellow pine forest at the Fort Valley Experiment Station in northern Arizona retained a thin layer of snow for 8 to 13 days after the open became bare. Similar data presented in several recent papers by Professor Church, of the Mount Rose Observatory, cover more extensive studies in the coniferous forests in the Lake Tahoe region of western Nevada, and show greater effects.

In order to find with some definiteness the effect, if any, of forests in representative portions of the Cascade Range on the melting of the winter snow cover, the Forest Service carried out studies of snow melting on three separate watersheds: The Tumalo area in central Oregon, the Wind River area in southern Washington near the Wind River Experiment Station, and the Yakima area on the headwaters of that river in central Washington. These locations permit the studies to show the value of forests to the irrigation interests, as well as to furnish a basis for comparing the effect of forests of this region with those of other regions.

The studies on the Tumalo area were carried through both the 1916 and 1917 seasons entirely by Forest Examiner W. J. Sproat of the Deschutes National Forest; those at the Wind River Experiment Station area by the writer in 1916, and by Forest Assistant C. J. Kraebel and Ranger A. E. Kloe in 1917; and those on the Yakima area, carried on in 1917 only, were conducted by Deputy Supervisor W. F. Ramsdell and Ranger W. G. Hellen, both of the Wenatchee National Forest. In each study the depth, density, and distribution of the snow cover were observed throughout the melting season at 8 to 20 typical observation points or stations.

Description of areas.

The first and third areas lie on the high eastern slopes of the Cascade Range; the Wind River area, however, lies in the region of west slope types along the Columbia River. The underlying rock is igneous in character and principally volcanic, with occasional outcrops of various size. Because of their altitude, and the consequently high annual precipitation, these timbered areas are an important source of water for the irrigation of the valleys below. Following is a brief description of the individual areas on which measurements were taken.

Tumalo Creek.—Snow stations lie at elevations of 6,000 to 6,800 feet, on the headwaters of a stream already furnishing water to a large irrigated area. In this region the average precipitation of 40 to 50 inches occurs principally in the form of snow, and at the higher elevations the snow cover may reach a depth of 15 to 25 feet. An irrigation reservoir to store the flood water of this creek, and already costing a half million dollars, has so far been only partially successful. Large areas of irrigable land need only water to become fertile.

The forest cover consists principally of broken stands of mountain hemlock up to 40 inches D.B.H. and 100 feet tall, and lodgepole pine averaging 10 inches D.B.H. and 60 feet tall, with an occasional western white fir. There is sometimes a scattered undergrowth of huckleberry bushes, willow, herbs, etc. The soil is a light pumice and usually rocky. Open areas are broken up with varying ground cover of grass, down logs, or forest reproduction up to 10 feet tall. Figure 1 shows the generally open character of much of the forest and the irregular burned over openings, usually but a few acres in extent. The study compares the snow melting in these openings with that under the forest cover.

Wind River.—Stations are in two main groups: On a flat at 1,200 feet elevation, and on mountain slopes at 2,500 to 3,000 feet. The first group is on a large alluvial bench covered with a typical Pacific slope forest. The Douglas firs are from 3 to 6 feet in diameter and up to 200 feet tall. Some western white pine and grand fir are intermixed; western hemlock frequently forms a thick understory. The moderate underbrush is principally vine maple and reproduction. Recent cuttings, some of which have been burned, furnish sites for the "open" stations. The sparse ground cover consists of weeds, vine maple and other brush.

The mountain slope snow stations are under a slightly lighter forest cover which contains noble fir in place of the grand fir. There are also some ledges and much loose rock in the local "shot" loam soil. Underbrush is but moderately dense and similar to that on the flat. The unprotected stations are, however, located in a large 15-year-old burn which is densely covered with vine maple, ceanothus, spirea, willow, cherry and reproduction.

The climate is generally moist but with a long drought through the summer, so that irrigation is practiced by some of the scattered valley ranches. The maximum depth of snow varies greatly, with the altitude and season, between depths of 2 to 5 feet and 6 to 12 feet on the flat and the high slopes, respectively. This snow makes up by far the greater proportion of the total precipitation.

The Yakima.—Stations are located immediately south of Lake Keechelus, an important irrigation reservoir on the headwaters of the Yakima River. The sites chosen are from 2,450 to 3,300 feet elevation (see Table 3) on the east slope of the Cascade Range near the Stampede Tunnel. Annual precipitation is about 50 inches, the largest part of which again is snow, accumulating to depths of 10 to 15 feet or more. The resulting water is partially but not entirely stored in reservoirs for use on the large areas of irrigable land in the lower valley. Any influence which will retard the melting will increase the efficacy of these reservoirs and make possible a more complete utilization of this snow water.

The forest cover is largely western hemlock, Douglas fir, western white pine, and some western red cedar, and is very similar to the Pacific slope forests. The undergrowth consists of huckleberry, willow, alder, vine maple, etc., with some herbs. The soil varies from sandy to clay loam and is frequently rocky. On this area also stations were studied both on the flat and on the steep slopes, facing mostly toward the east.

The "open" stations are on old burns and logged-over areas, with ground cover varying from grass to a fairly heavy mixture of goat brush with huckleberry bushes and forest reproduction up to 13 feet high.

[1] Jaenicke, A. J., and Foerster, M. H., The Influence of Western Yellow Pine Forest on the Accumulation and Melting of Snow. MONTHLY WEATHER REVIEW, March, 1915, 43: 115.

[To face p. 324.]

FIG. 1.—Looking northeast across the north fork of Tumalo Creek. Some dense timber appears on the left, but most of the forest cover is very light. (Photo. by Sproat, Apr. 13, 1916.)

FIG. 2.—Small mounds of snow beneath the litter fallen from the forest cover. The unprotected snow has melted much more rapidly. (Photo. by Kraebel, May 2, 1917.)

Method of observations.

In order that the data might be definite and closely comparable, snow stations were located in the open and in the forest in pairs, the two stations being similar in all important respects except in forest cover. Aspect, degree of slope, and distance to trees, stumps, edge of timber, possibilities of drifting, and other factors each received careful attention. Frequently another pair of stations served as a check.

Snow depths were measured regularly at intervals of usually one week or less, from the period of greatest depth throughout the duration of the melting season of 9 to 17 weeks. In all cases where the snow was less than 5 feet deep from two to five or more measurements were taken at each station to give an average figure for that particular site. Permanent graduated stakes marked each place of measurement on the Tumalo area and the center of each station on the other areas.

The snow density, or water equivalent, was measured at each regular observation close to at least four typical stations. Both the standard United States Weather Bureau apparatus and sampling cans were used for the purpose, some difficulties being encountered and others avoided by each method. Because of deep snow and unsuitable apparatus on the Tumalo area these measurements were so difficult and irregular that only average figures were used.

Data.

Full reports for each of the studies are available in the Forest Service files. For the sake of brevity and clearness the results are given here, summarized by areas studied.

Tumalo.—The four pairs of stations observed on this area in the spring of 1916 were typical of small burns or open areas of from 1 to 4 acres in extent, and the immediate borders of the adjacent stands of mature timber. The greatest average depth of snow measured in the timber was 121.2 inches on April 5, 10 inches less than was measured in the open on the same date. On June 22 the first open station became bare of snow; on July 18 no snow was left on any of the stations in the open. As the snow disappeared from the individual stations in the open there remained at the corresponding forested stations an average of 19.3 inches of snow. At an average density of 45 per cent, this is equal to 8.7 surface inches of water; 2.1 inches, about 25 per cent, still remained two weeks later at the time of the last observation.

In the spring of 1917, with slightly less snow and a briefer melting season, the equivalent of 5.2 inches of water was retained by the forest-covered stations after the "open" stations became bare; at the end of the second week all were bare. In 1917 observations included eight pairs of stations, the new open stations being in larger openings.

Wind River.—The results for 1916 in the densely forested Wind River region are as follows: From a maximum average depth of 70.8 inches of snow[1] an average of 28.2 inches remained at the forested stations as the corresponding stations in the open became bare. Part of this remained for six weeks longer. The retarding effect of the forest cover was twice as strong on the deeply snow-covered mountain slopes as on the flat. About 66 per cent of the maximum water equivalent was conserved on the one and 38 per cent on the other.

In 1917 administrative exigencies permitted complete examinations of only three pairs of stations on the flat. The maximum average depth of snow in the forest was 25 inches. The stations in the open became bare in April, leaving an average of 6.2 inches at the stations in the forest. This was equal to 3 inches of water, or 40 per cent of the maximum water equivalent.

Yakima area.—The observations on the Yakima watershed cover the melting season of 1917 only. From a maximum of 88 inches of snow at the forested stations in early April, there was still an average of 19 inches left at each forested station when the corresponding station in the open became bare—about June 1. This snow, equal to 6.9 inches of water, gradually melted during the next four weeks. (Table 2 shows the results in detail.)

Correlation of results.

Table 1 summarizes the water value of the snow cover retained by the forested areas. The 7.5 inches of water equivalent, found to be the mean for all stations, lasted on the average for 17 days and at some forested stations for more than 42 days. The value of forests appears to be greatest on Wind River, and in 1916, probably because of the high mountain slope stations with deep snow mantle under heavy forest cover, and least on the Tumalo area, under the "dry slope" conditions.

TABLE 1.—*The water equivalent of the mean depths of snow retained by the forested stations when the corresponding open stations became bare, and for three weeks thereafter, expressed in inches and in per cent of the maximum snow cover.*

Study.	Maximum water equivalent.	Weeks after open stations became bare.							
		0		1		2		3	
	In.	*In.*	*P.ct.*	*In.*	*P.ct.*	*In.*	*P.ct.*	*In.*	*P.ct.*
Tumalo, 1916	47.0	8.7	18	6.0	12	2.1	4	.....	.....
Tumalo, 1917	44.0	5.2	12	0.1	.....	.....	.....	.....	.....
Wind River, 1916 [1]	25.8	13.5	52	9.5	37	8.0	31	5.3	21
Wind River, 1917	7.6	3.0	40	0.6	8	.....	.....	.....	.....
Yakima, 1917	24.6	6.9	28	3.2	12	1.6	7	0.3	1
Mean	29.8	7.5	30	3.9	14	2.3	9	1.1	4

[1] Average of flat and mountain slopes.

As an example of the data on which these averages are based, Table 2 gives the averages of the measurements at each station on the Yakima area during the season of rapid melting. Measurements on April 10 represent the maximum snow cover of the year. Other measurements, from February to May 3, are omitted, since they do not relate closely to the season of rapid melting.

Measurements of snow density (or water equivalent) were taken each week at practically every station on this area, and, after the middle of May, were repeated from two to four times at each station. The density was, of course, least in the early spring and greatest at the end of the melting season, increasing from averages of 30 to 40 per cent in March or April to 45 to 55 per cent in June or July. Measurements of this factor have varied to a considerable degree with site and season, and often without a suitable cause being apparent. Averaged figures have been preferred for consistent results. In general the snow density is from 1 to 5 per cent higher in the open than in the forest.

A tabulation of what have been found to be the more influential site factors of the stations on the Yakima areas appears in Table 3. Similar and more detailed observations (including also rocks, soils, and ground cover), were made of each of the 36 stations on the other areas and appear in the separate reports.

[1] Water equivalents are shown in Table 1.

TABLE 2.—*Yakima Watershed: Depths of snow at stations in the open and in the forest—Averages of each and average snow densities (depths in inches).*

Station.	April 10.	May.			June.				July 3.
		9	17	20	4	12	18	25	
1 open	85.0	85.0	57.5	12.5	2.0	0	0	0	0
2 open	130.0	67.0	37.0	0	0	0	0	0	0
3 open	114.0	84.0	63.0	11.8	0	0	0	0	0
4 open	127.0	57.0	32.5	0	0	0	0	0	0
5 open	106.0	54.5	27.7	0	0	0	0	0	0
6 open	108.0	67.0	46.0	14.1	0	0	0	0	0
7 open	104.0	87.0	63.0	31.0	8.8	0	0	0	0
8 open	100.0	72.0	50.0	23.5	10.8	0	0	0	0
9 open	94.0	57.0	34.0	6.0	0	0	0	0	0
Average	107.6	70.9	45.6	10.7	3.4	0	0	0	0
Density (per cent)	31	40	46	43	52				
1 forest	92.0	79.0	71.0	46.7	39.0	28.7	7.7	0.3	0
2 forest	80.0	54.0	39.0	7.7	4.2	0.2	0	0	0
3 forest	88.0	60.0	48.0	16.8	4.5	0.1	0	0	0
4 forest	78.0	41.0	23.3	1.0	0	0	0	0	0
5 forest	72.0	46.0	31.0	23.6	13.2	10.2	0.2	0	0
6 forest	99.0	73.0	58.0	37.0	22.4	4.8	0.3	0	0
7 forest	101.0	73.0	56.0	43.0	29.2	18.7	5.1	0.1	0
8 forest	98.0	68.0	61.0	45.7	43.0	28.3	23.0	12.2	0.2
9 forest	84.0	61.0	50.0	28.0	26.3	16.2	12.6	5.7	0.2
Average	88.0	61.7	48.6	27.7	20.9	11.4	5.4	2.0	
Density (per cent)	33	40	40	40	38	36	32	50	53

TABLE 3.—*Yakima watershed snow stations. Influencing site factors and results upon snow cover.*

Station.	Altitude.	Aspect.	Slope.	Forest density.	Snow conserved, 1917.	
					Depth.	Weeks.
			Per cent		*Inches.*	
1 open	3,300	N. 70° E.	21			
1 forest	3,300	N. 30° E.	30	0.8	28.7	3
2 open	2,900	S. 65° E.	100			
2 forest	2,900	S. 60° E.	84	0.5	7.7	3
3 open	2,900	N. 40° E.	58			
3 forest	2,900	N. 40° E.	70	0.45	4.5	2
4 open	2,650	N. 50° E.	4			
4 forest	2,650	N. 60° E.	3	[1] 0.5	1.0	1
5 open	2,500	West	35			
5 forest	2,500	S. 55° W.	20	0.55	23.6	4
6 open	2,500		0			
6 forest	2,500		0	0.65	24.4	3
7 open	2,650	N. 55° E.	25			
7 forest	2,650	East	25	0.6	18.7	3
8 open	2,450		0			
8 forest	2,450		0	0.7	28.3	4
9 open	2,500		0			
9 forest	2,500	North	3	0.8	26.3	5
Average	2,600		27	0.62	19.0	3.1

[1] On three sides the timber cover extends for only about 120 feet from the center of the station.

Although the study does not show any relation between the amount of snow conserved and either altitude, aspect, or slope, it appears that the density of forest cover does produce a distinct effect. In Table 4 a grouping of the stations according to density of cover into four classes brings out this relation quite clearly.

TABLE 4.—*Depth of snow conserved by the stations grouped according to forest cover.*

Stations.	Average forest density.	Snow conserved.	
		Inches.	Weeks.
1 to 9 open	0.00	0.00	0.0
2, 3, 4 forest	.49	4.4	2.0
5, 6, 7 forest	.60	21.5	3.3
1, 9, 10 forest	.77	27.8	4.0

On other areas this relation is hardly as clear as here or as pronounced, though it is evident all through the study.

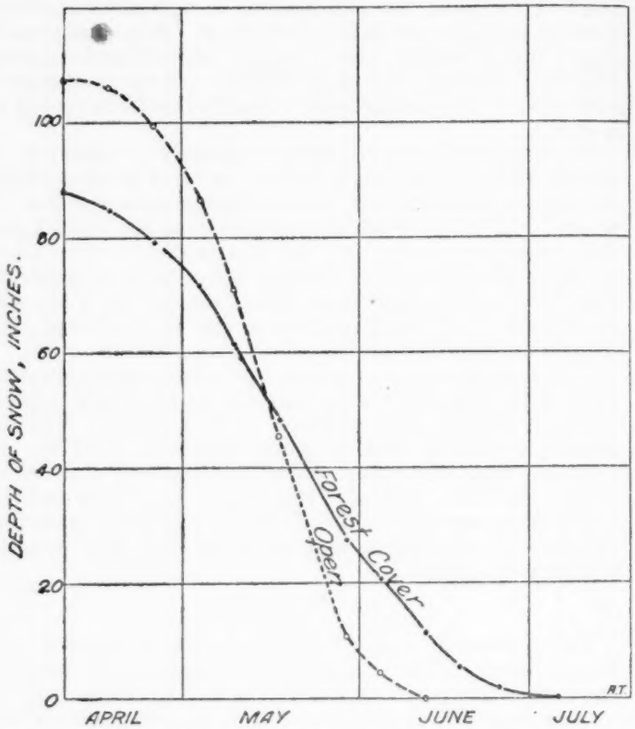


FIG. 3.—Depth of snow at station in the forest and in the open, Yakima watershed, 1917.

The curves of figure 3 show graphically for the Yakima study the more rapid melting at the open stations and the proportion of snow retained at the forested stations. As shown in Table 1, similar curves drawn for each of the other areas would tell very much the same story. The curves given also bring out the frequently observed fact that during the early spring there is a greater depth of snow at the stations in the open than at those under timber. This condition existed on the other areas excepting at high altitudes at Wind River where dry snow with less sunshine seems to have permitted a larger proportion of the total snowfall to reach the ground under the trees.

Comments.

The most important weaknesses of this study lie in the short period covered by the observations—two seasons at the most, and in small practically unavoidable differences in the site factors of the stations of each pair. Because of the severe conditions and amount of labor necessarily involved, it quickly appears that a long series of complete and accurate observations will be quite expensive. Such measurements might possibly be made in connection with annual snow surveys for irrigation purposes. The irregularities in factors of the stations are balanced through the selection of a considerable number of stations (54) in the different regions and by three different men.

Contradictory results appeared at one station: The lowest pair of stations on the Tumalo area became bare in 1916 in the same week, but at the last measurement the open station retained slightly more snow. This may

have been due partly to its location in an opening of less than 125 feet radius, and partly to the location of the corresponding forested station less than 100 feet within a stand of thin crowned lodgepole pine. Under the latter conditions but slight protection is received from either direct sunshine or currents of warm air. A similar statement holds good for station *4 forest* of the Yakima area, as shown in Tables 2 and 3.

Because of defects in the sampling tube used, measurements of density on the Tumalo area were too irregular for complete confidence. The limits of the average densities used are from 36 per cent in the early measurements to 45 per cent for the last measurements.

Drifting by the wind was of comparatively small importance throughout the study. Very large and deep snow drifts occur on comparatively small areas near the summit of the Cascade Range, but are not found on the middle slopes or on these areas. The lesser blowing and drifting of snow, chiefly in the open areas, appears to be practically self-compensating.

The results of this study are in general accordance with Swiss figures quoted by Fernow[1]—that the retardation of snow melting in forests is 5 to 8 days in general and may be several weeks—and also with the above mentioned observations by Church. In agreement with the latter is the tendency of the snow in the forest to be deepest and last longest in the small openings of the denser forests. This tendency was especially noted on the Wind River area and may partly account for the late melting of the snow in the small open areas characteristic of the Tumalo area. In large openings the protecting influence from the forest would be dissipated and melting consequently more rapid.

An unusual factor in delaying the melting within the Douglas fir type of forest is the protection given by the irregular layer of even very slight bits of moss, twigs, bark, and other litter weathered from the trees. Fragments like those shown in figure 2, which in the open would materially hasten melting by absorbing solar heat, in the forest serve as a crude but effective insulation from the warmer air currents above the snow. In a more open forest this effect is less prominent.

An opposing influence appears in the ability of bushes, tree trunks, and other large objects to hasten melting by radiating or reflecting into the snow the heat which they receive from various sources. Hollows or bare spots around trees, etc., are frequently noted in the spring. They seem to be important in all coniferous forests but especially in those of the yellow pine type.

Application of results.

Expressed in irrigation terms, the figures given in Table 1 mean that on the areas studied the average square mile of forest cover retained the equivalent of between 720 and 160, averaging 400, acre-feet of water in the form of snow after the open areas had become bare. Neglecting losses through seepage and evaporation, the average of 400 acre-feet is sufficient supply for about 150 acres of cultivated land for the entire season, or for about 650 acres for one month during the peak of the irrigation season (during the summer low-water period). Of course some loss is to be expected in the natural flow of the water down to the lower valley; but it will, at a time when the ground is already saturated, be much less than the normal loss. It is also probable that some of the water will flow down stream too early to be of greatest use in irrigation. Making considerable allowance for these losses, it appears that the forest cover is a very important and very valuable factor in increasing water available for irrigation.

In terms of time, the effect of the forests was to spread the 400 acre-feet of retained snow water through a period averaging 17 days in length. The retardation of this amount of snow is sufficient to be of great importance to irrigation interests, especially as it is generally understood that a forest cover tends to "flatten out" the crest of a flood, and thus to increase the minimum flow at periods of low water. A forest cover thus supplements the possible artificial reservoirs. This study furnishes measurements, however, not of stream flow but only of the material out of which stream flow is made.

[1] Fernow, B. E., Forest Influences, Bull. 7, Div. of Forestry, p. 137.

Summary.

The study of snow melting in the open and in the forests of three areas on the Columbia River watershed showed that the snow remains an average of 17 days longer in the forest.

Drifting occurred only on the higher ridges of these areas and chiefly in the open, though the late snowbanks in the forest had very much the appearance of drifts. Because of the retention of snow on the crowns of trees and the resulting increased evaporation, the snow cover usually reached a depth greater in the open than in the forest.

The depth of snow retained was considerably greater in a dense forest than in an open forest, at least during the latter part of the melting season. For the areas studied, the snow remaining in the forested stations, at the time the open stations became bare, was equal to 7.5 surface inches of water or about 30 per cent of the maximum snow blanket. With the forest areas at higher altitudes and with stations located so as to prevent completely the influence of open areas on the forested stations, and vice versa, the effect was found to be noticeably greater than this.

SNOWFALL ON MOUNT RAINIER, WASH.

By LAWRENCE C. FISHER.

[Dated: Weather Bureau Office, Seattle, Wash., May 24, 1918.]

Mount Rainier, standing to the west of the main range of the Cascades, rises to a height of 14,408 feet in nearly unobstructed view from the shores of Puget Sound. The low peaks about its base, which were originally a part of the mountain before glaciers cut its flanks, appear to merge into the contour of the mountain when viewed from the Sound, and the mountain itself towers high above the main range of the Cascades 12 miles to the east. The upper and more conspicuous half is clothed with an eternal mantle of snow, while a score of glaciers extend for several miles farther down the deep valleys. En route to the sea, a fraction of the power of its never-failing streams has been captured and transformed to illuminate towns and cities and turn the wheels of industry. One marvels at the rushing torrents of water, and wonders what may be the quantity of snow and rain this great and unshielded mountain takes from the passing winds each year. It is a subject worthy of extended observations and study.

A daily record of snowfall was made during most of the season 1916–17 at Paradise Inn on the south slope of Mount Rainier at an elevation of 5,500 feet. Although

observations were not begun until November 24, 1916, the total measured snowfall from that time to the last snowstorm before midsummer in 1917 is apparently greater than for any other station in the United States for any entire season, with the single exception of Tamarack, Cal., in 1906–07. Below is the snowfall record for Paradise Inn by months in inches:

Snowfall at Paradise Inn, Mount Rainier.

1916			1917							Total.
On ground Nov. 24.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	
36	[1] 61	123	131	77	206	94	14	47.5	0	789.5

[1] 7 days.

Some of the more notable snowfall records made prior to this are the following:[2] At the Musick station in Oregon, elevation 5,000 feet, the total snowfall for the season 1912–13 was 612.7 inches; at Government Camp, Oreg., elevation 3,890 feet, 590 inches were recorded in 1898–99; the greatest snowfall at Summit, Cal., in 44 winters, elevation 7,017 feet, is 783 inches in 1879–80; at Tamarack, Cal., elevation 8,000 feet, the greatest snowfall in eight winters is 884 inches in 1906–07;[3] on the summit of Pikes Peak, Colo., elevation 14,134 feet, 743.3 inches of snow fell in the season of 1892–93.

The Paradise Inn record is the first obtained west of the summit of the Cascades in Washington at so great an elevation. The more elevated mountain snowfall stations have been limited to points along railway lines, to mining camps, and to mountain inns which usually are primarily summer resorts. In this State the passes permit railways to cross the mountains at comparatively low elevations. The highest mining camps from which records have been obtained lie on the eastern or leeward slopes of the Cascades, where, though the snowfall is very heavy, it is less than on the western slopes. The construction of a large and substantial hotel building in Paradise Valley in the summer of 1916 made possible this interesting observing station. Mr. E. H. Frank, custodian of the inn for the winter, proved a careful and faithful observer. He erected a graduated snow stake at a point approximately 200 feet to the northwest of the westerly wing of the building, where conditions appeared to be most favorable for obtaining average snowfall measurements. Both the amount of freshly fallen snow and the accumulated depth were measured daily throughout the period. Owing to the lateness of the season when the station was established, no rain-and-snow gage was provided, but the usual self-registering maximum and minimum thermometers were supplied by the Weather Bureau and were exposed on the northeast end of the hotel. The observer improvised a shelter to screen the thermometers from the direct rays of the sun. As the depth of the snow increased the instruments were attached higher and higher on the wall of the hotel. Egress and ingress to the hotel was by means of tunnels through the snow to windows of the wing designed for the accommodation of guests. These tunnels required frequent reconstruction.

[2] See also Palmer, Andrew H., The region of greatest snowfall in the United States. This Review, May, 1915, 43:217-221.—Editor.

[3] In a letter dated Aug. 27, 1918, Mr. Palmer states that in his paper above quoted this record was overlooked in the selection of extreme maximum snowfall, although included in determining the average seasonal snowfall.—Editor.

Apparently a complete record was not made of the number of times rain fell at the station, but temperatures indicate the possibility of rain in each month. In February notation of rain was made on three dates, and again in April rain was noted three times. It is quite probable that rain fell in other months to some extent.

The national park ranger, Mr. J. B. Flett, has the full equipment for cooperative observers at Longmires Springs, the elevation of which is 2,761 feet, and has kept a meteorological record for a number of years. In addition, for several seasons he has made measurements of snowfall depths on the 15th and last day of each month near the foot of Nisqually Glacier, elevation 3,908 feet, and near Narada Falls, elevation 4,572 feet. Readings for these two dates in each month during the season of 1916–17 for the four different points of observation on the south slope of Mount Rainier are shown graphically in Figure 1.

As the daily readings are available for the Longmires and Paradise stations, their graphs have been drawn to include the maximum depth at the time observed. Readings at the foot of Nisqually Glacier and Narada Falls began with January 31 and ended with June 30. No data are available for May 31. It will be noted that fluctuations in graphs for the regular cooperative stations at Longmires Springs and Paradise Inn, the lowest and the highest stations, respectively, harmonize most closely.

Although daily snowfall measurements have never been made previously at Paradise Inn, there are grounds for the belief that the season 1916–17 was not one of maximum snowfall. To be sure, the snow remained on the ground longer than usual, even as late as or a few days later than the preceding season, when snowfall was unusually great; but its long continuance was probably due to the low temperatures that prevailed most of the season, and to the heavy snowfall in March. Records for other mountain snowfall stations show considerably more snow in the season 1915–16 than in 1916–17. At Longmires Springs the total snowfall from November to May, inclusive, in the season 1915–16 was 327 inches, as compared with 296 inches for the same period in 1916–17; and the water content of all kinds of precipitation was 78.01 inches for the former season as compared with 58.88 inches for the latter. From February to May, inclusive, the temperature averaged 3° lower in 1917 than in 1916, and this accounts for the smaller snowfall of 1916–17 remaining on the ground a little longer than the heavier fall of the season before. At Goat Lake, elevation 2,900 feet, in the season of 1915–16, 622 inches fell, while in 1916–17 the amount was 443.5 inches, which is less than the seven-year average. At Tye, elevation 3,115 feet, the earlier season had 520.5 inches and 1916–17 had 471 inches. At Cascade Tunnel, elevation 3,373 feet, the 1915–16 season had 717 inches and 1916–17, 594 inches. Therefore it seems probable that the snowfall at Paradise Inn for the season 1915–16 exceeded that for 1916–17, and that this total of 789.5 inches can not be considered to have occurred in a season of maximum snowfall.

Again, the question arises whether Paradise Inn is located on the slope that would receive the greatest precipitation. Normally the heaviest precipitation in Washington is found on the windward side of mountains. The prevailing direction of surface winds is generally southwest or west, and the clouds move from this quarter even more frequently than the surface winds. During the winter of 1916–17 the daily eye observations of the wind at the Inn gave an average direction somewhat south of west. It

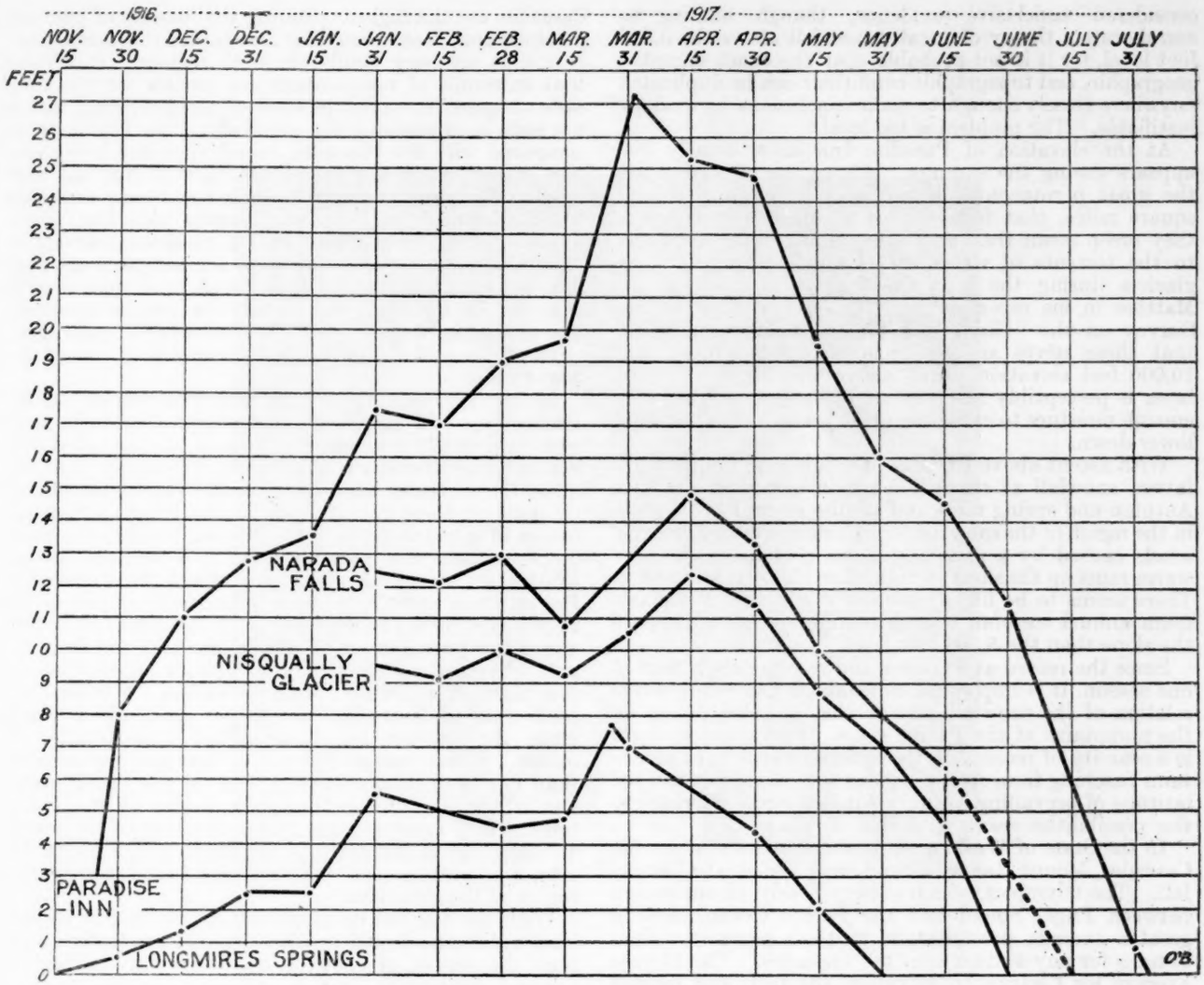


FIG. 1.—Depths of snow on Mount Rainier, Wash., 1916–17, at four elevations.

would be reasonable to expect the maximum precipitation approximately on the southwest slope. But the Paradise Inn station is located 1 mile east of the meridian passing through the summit, the distance to which is 4½ miles. In this respect it does not conform to the theoretical location for maximum precipitation. Indian Henry's Hunting Ground is located on the southwest side of the mountain, the elevation of the camp being 200 feet lower than Paradise Inn. It is generally understood among mountaineers that snow disappears earlier at Paradise Inn than at Indian Henry's, and in Summerland, at about the same elevation on the east slope, it disappears even earlier than in Paradise Valley. In the latter part of July, 1917, when there was considerable bare ground in Paradise Valley, Indian Henry's Hunting Grounds were still entirely covered with snow. There was less snow at this time in Summerland than in Paradise Valley. These facts at least harmonize with the principle of maximum precipitation on the windward slope and minimum on the leeward.

What the differences in the amount and intensity of sunshine may be at these three places is not known. The suns rays at midday are most effective on a south slope, but this alone is insufficient to account for all the phenomena; it does not explain the earlier disappearance of snow in Summerland on the east slope. Furthermore there is more sunshine recorded at Weather Bureau stations in this State in the afternoon than in the forenoon. A preponderance of sunshine in the afternoon would favor melting on the southwest slope; but, as has been stated, the snow in Indian Henry's is slowest to melt. What influence winds may have in this respect is unknown. From the evidence at hand, it appears that snowfall is greater on the southwesterly slope of the mountain than at Paradise Inn.

So far as known no observations have been made that would indicate whether there is a further increase in the amount of snowfall above the 5,500 foot level. In California snowfall records have been obtained as high as 7,000 and 8,000 feet, and they show an increase in the amount of snowfall over that at stations approximating the 5,500 foot level.[3] Yet one would hardly expect the maximum precipitation and snowfall in Washington to occur at the same height as in California, owing to the differences in latitude and the resultant climatic conditions. Records for other mountain regions can not be

[3] See Palmer, Ibid., p. 217.

considered conclusive evidence, though tending to corroborate a theory of greater snowfall above the 5,500 foot level, for it is not probable that the exact climatic, geographic, and topographic conditions can be duplicated anywhere closely enough to make conclusions by analogy justifiable. The problem is too local.

At the elevation of Paradise Inn snow usually disappears during the summer. Above this elevation are the great permanent snowfields, each covering several square miles, that feed a score of glaciers with ice as they creep down the valleys in summer, and contribute to the torrents of water that issue from beneath the glaciers during the warmth of the day. Mr. F. E. Matthes in his report for the United States Geological Survey on the "Glaciers of Mount Rainier" indicates that these névés are conspicuous between 8,000 and 10,000 feet elevation, while above that level the snow layer is perceptibly less, the air being too cold to carry enough moisture to cause the great precipitation received lower down.

With ascent above Paradise, the lowering temperature favors snowfall at times when rain occurs at the inn. Autumn and spring rains at Paradise are apt to be snow in the region of the snow fields. Even in winter southerly winds caused by a pronounced low pressure area carry warm rains up the slope as high as or higher than the inn. There seems to be little reason to doubt that the maximum annual snowfall will be found to occur higher up the slope than the 5,500-foot level.

Since the record at Paradise Inn covers only a part of one season, it is impossible to establish the comparative relation of the snowfall here to that at other points on the mountains of the Pacific slope. Furthermore, there is a scarcity of records on the extensive system of mountains reaching from Arctic regions southward beyond the latitude of prevailing westerly winds. Some reference to the possibilities seems desirable, however.

In the State of Washington it would seem that for the Cascades, Mount Rainier should show the greatest snowfall. The Olympics, which occupy nearly all the region between Puget Sound and the Pacific Ocean, show a greater average precipitation to their southwest than obtains for any station near the Cascades. The 12-year average for Clearwater, elevation 135 feet, and located a few miles from the seacoast, is 128 inches. A 9-year record at Quiniault, about 25 miles inland at an elevation of 300 feet, but where the country is mountainous, shows an average of 135 inches. These stations have considerably greater precipitation than has thus far been obtained at any station in the Cascades at any elevation. At Longmires Springs, on the south slope of Mount Rainier, elevation 2,761, a 5-year record yields an average of 78 inches; Yale's 10-year average at 375 feet elevation, farther south, yields 94 inches; at Snoqualmie Pass, elevation 3,000 feet, a 3-year record averages 87 inches; the 9-year record at Goat Lake at 2,900 feet elevation averages 94 inches; Cedar Lake's 14-year record at 1,546 feet averages 107 inches. No measurements have been made at equal elevations in the Olympics, but it is evident that at corresponding elevations precipitation is considerably greater than in the Cascades.

The factor of temperature must modify somewhat the proportion of precipitation that occurs as snow. In comparing mean temperatures at stations on or near the coast with those at approximately similar elevations near the Cascades the mean temperature for the most of the three winter months for the more inland stations is the colder, but in all other months of the year the monthly mean temperatures for stations on the west slope of the Cascades are the higher. During the months of greatest precipitation, November and December, the mean temperatures are very similar in both regions. It is true that extremes of temperature are greater for the Cascade stations; however, in view of the foregoing, one is not safe in minimizing the snowfall on the Olympics as compared with the Cascades, based upon the consideration of temperature, especially in view of the fact that Mount Olympus exceeds 8,000 feet in elevation. But very few official readings of snowfall depths have been made for the Olympics. These are for moderate elevations only, and while affording no basis for comparisons, they indicate a very heavy snowfall. Judgment may well be reserved as to which range has the greater snowfall. The obtaining of daily readings of snowfall in the rugged Olympics is still of the future and probably not of the near future.

As one proceeds northward from Washington on the Pacific slope, the period without precipitation in summer soon practically vanishes. There is no so-called dry season in southeastern Alaska and it appears that the quest for a greater snowfall than in Washington should be pursued there rather than to the south, where the season of snowfall is shorter. One can not hope to point out the region of greatest snowfall in a territory so vast as Alaska with records so few and at low elevations only. Precipitation records in the southeastern portion of the Territory show a 12-year average of 151 inches at Loring, and a five-year average of 165 inches at Ketchikan. A parallel record covering only 20 months shows that the precipitation at Jumbo Mine, elevation 1,500 feet, exceeds that of Ketchikan by 19 per cent, which would make the average for Jumbo Mine approximate 190 inches. These stations show a heavier precipitation than has been measured elsewhere on the Pacific slope, and it seems probable that with ascent of the mountains, which in some cases rise almost out of the ocean, and lie close to the paths of storms from the North Pacific, a greater snowfall will be found than for any other region of the continent.

With the further development of the Mount Rainier National Park, it will become possible gradually to extend the survey of snowfall on the mountain, and an unusual opportunity will be afforded for the study of variations in precipitation with elevation and exposure.

ON SEVERE WINTERS.[1]

By G. HELLMANN.

[*Reprinted from* Science Abstracts, Sect. A, June 29, 1918. § 624.]

A "character number" to express the degree of severity of any winter is obtained in the following way: The mean temperature in degrees centigrade for each day of the months November, December, and January is taken; of these the negative values are selected and added together; the result, viz, the sum of the negative daily means, is the character number. Of the last 150 winters in Berlin, 24 are classified as "very severe." The most severe was the winter of 1829–30, and that of 1788–89 was almost as severe. The winter of 1916–17 comes out only as a moderately severe one. Since the middle of the nineteenth century the number of very severe winters has been much reduced; in the period 1788 to 1845 that number was great, namely, 17. A very severe Berlin winter is associated with the presence of a prolonged snow covering, and a westerly position of the continental high-pressure system.—*R. C[orless.]*

[1] Preuss. Akad. Wiss., Berlin, 1917, 52: 738-759.

FIG. 2.—Showing snow on trees at Paradise Inn, Mount Rainier, March, 1917. Elevation about 6,000 feet.
(Photo. by J. B. Flett, National Park Ranger.)

FIG. 3.—Snow on bridge over Edith Creek, Mount Rainier. Top rail of bridge is 4 feet in height. Note figure of woman on the bridge. (Photo. by J. B. Flett, National Park Ranger.)

FIG. 4.—Paradise Inn, March, 1917, looking north toward summit of Mount Rainier. This was taken about time of deepest snow. (Photo. by J. B. Flett, National Park Ranger.)

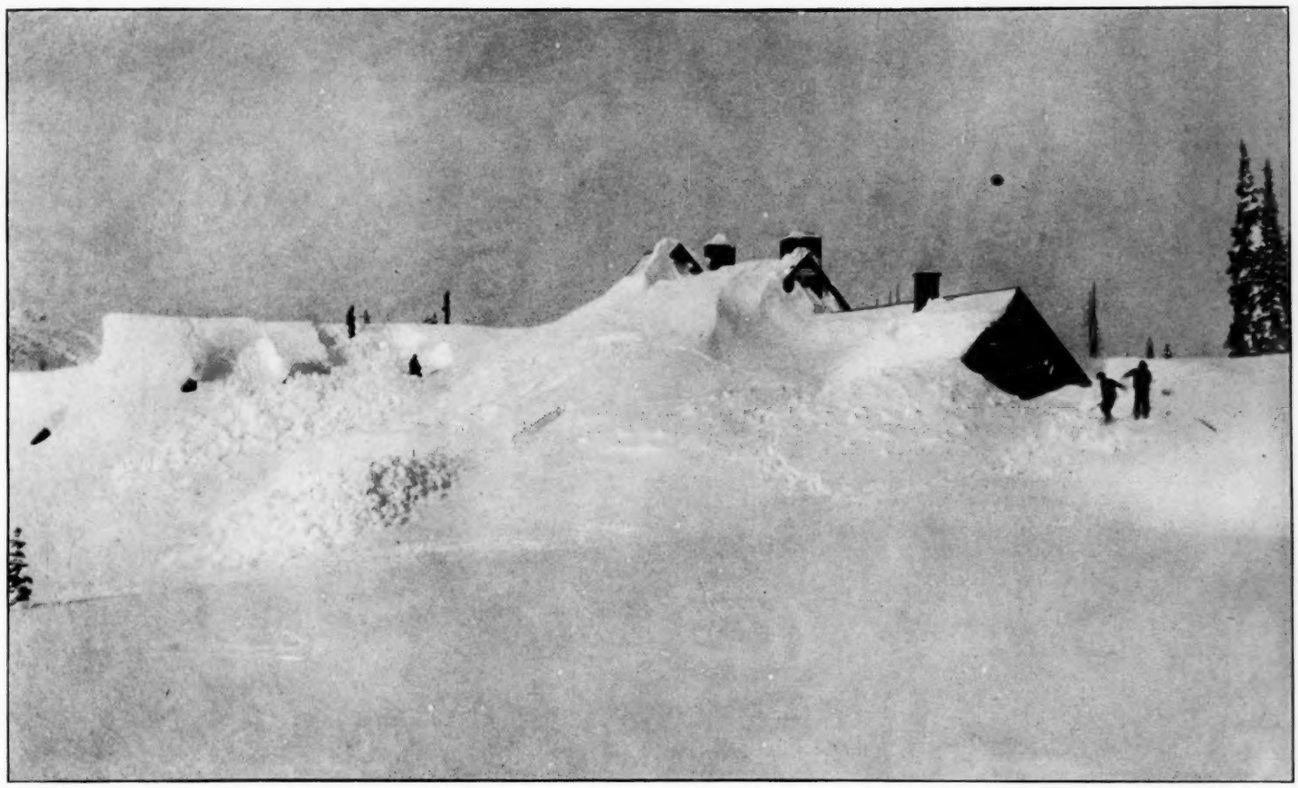


FIG. 5.—Paradise Inn, Mount Rainier, at time of maximum snow depth, April 2, 1917, looking southwest. (Photo. by A. H. Barnes.)

SECTION III.—FORECASTS.

FORECASTS AND WARNINGS FOR JULY, 1918.

By H. C. FRANKENFIELD, Supervising Forecaster.

[Dated: Weather Bureau, Washington, August 5, 1918.]

GENERAL PRESSURE DISTRIBUTION OVER THE NORTHERN HEMISPHERE EXCEPT EUROPE AND INTERIOR ASIA.

Over the Pacific Ocean pressure was subnormal to a moderate extent, except for a few days over the central portion, and again during the last five days of the month, when it was slightly above normal. A severe typhoon was reported during the first week of the month over the Philippines and the China Sea regions. No details have been received as yet, but the reports from Manila showed barometer readings of 29.68 and 29.53 inches on the 7th and 8th, respectively. Over the Aleutian Islands pressure was also low except during the first week of the month, while over Alaska moderately high pressure prevailed until near the close of the month, except over the extreme southern portion, where pressure averaged slightly below normal.

Over the United States proper there were no marked fluctuations in pressure, and, as a whole, the barometer ruled slightly above normal except on the Atlantic coast, where it was moderately low except during the fourth week of the month.

Over the North Atlantic Ocean pressure was high after the first week of the month, except over the extreme southern portion, where it was about normal.

WARNINGS FOR THE WASHINGTON DISTRICT.

STORM WARNINGS.

There were no marked disturbances during the month except on the morning of the 1st, when a disturbance from the Northwest was central over extreme eastern Lake Superior. Northwest storm warnings were ordered at 9:30 a. m. for Lake Huron and eastern Lake Superior and at Erie, Pa., and Buffalo, N. Y., with instructions to lower them at sunset on Huron and Superior. These warnings were fully verified during the day, Buffalo reporting a wind velocity of 60 miles an hour from the southwest. On the morning of the 31st there was a moderate depression off the Middle Atlantic coast with an apparent northeastward movement, and at 10 a. m. northeast storm warnings were ordered on the New England coast from Block Island, R. I., to Provincetown, Mass. Moderate northeast gales prevailed during the day, and at Cape Henry, Va., there was a 48-mile wind from the north. The warnings were lowered at 9 p. m.

FROST WARNINGS.

A light local frost at Sault Ste. Marie, Mich., on the morning of the 31st was not forecast.

WARNINGS FOR OTHER DISTRICTS.

Chicago, Ill., forecast district.—No frost warnings were issued during the month, except for northwest Wyoming on the 24th and for the Wisconsin cranberry marshes on the 29th.—*Charles L. Mitchell, Forecaster.*

New Orleans, La., forecast district.—During the greater part of the month the weather in this forecast district was under the influence of areas of high pressure, which extended over the central portion of the country, or over the Gulf States, or over the Southeast. These conditions resulted in much clear weather, with an excess in temperature and a marked deficiency in precipitation in most sections. There were no storms, except local thunderstorms, and no warnings were needed or issued.—*R. A. Dyke, Forecaster.*

Denver, Colo., forecast district.—Weather conditions remained unsettled throughout the month in all parts of the district. The rainfall, generally in the form of thunderstorms, was well distributed during the first half of the month except in New Mexico and the mountainous districts of Colorado. In the latter half the thundershowers were confined principally to the eastern Rocky Mountain slope.

No special warnings were issued.—*Frederick H. Brandenburg, Forecaster.*

San Francisco, Cal., forecast district.—July, 1918, was a month of unusual weather conditions in this district, especially in the north Pacific and plateau States, where the changes in both weather and temperature were rapid and erratic. The dominant feature was the recurrence of troughs of low pressure over the interior; first appearing over the valley of the Colorado and then extending northward over the Sierra Nevada and Cascade Mountains, causing unsettled and showery weather with numerous thunderstorms in the mountain and plateau regions.

Sometimes these troughs would merge with depressions moving southward over British Columbia and Alberta, and then move eastward near the international boundary; at other times after oscillating back and forth over the plateau for several days they would move rapidly eastward through New Mexico.

Another peculiar feature was the repeated appearance of an area of high pressure off the northern California and Oregon coasts moving rapidly inland, to be followed within 12 or 24 hours by its recession back into the ocean.

The above-described conditions were frequent during the second and third decades and caused unsettled weather and temperature changes that were difficult to forecast.

Showers and thunderstorms were frequent in the northern portion of this district and in Nevada on the 9th and 10th; and in Washington, Oregon, and northern Idaho from the 22d to the 26th, inclusive, and were beneficial to crops and ranges.

Forest fires were frequent in the first half of the month, but the rains at the beginning of the third decade brought them under control in the northern portion of the district.

There were indications on the morning of the 9th that the long drought in the north would be broken, and telegrams to that effect were sent to the forest supervisors in Washington, Eastern Oregon, Idaho, and western Montana. The telegrams read "Probably showers and thunderstorms and cooler with local gusty southwesterly winds to-night and Wednesday." The forecast was verified.

No storm warnings were issued and none were necessary.

Water is becoming very scarce for irrigation and power purposes in all sections.—*G. H. Willson, Forecaster.*

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS DURING JULY, 1918.

By ALFRED J. HENRY, Meteorologist in charge.

[Dated: River and Flood Division, Weather Bureau, Aug. 24, 1918.]

Excepting the annual rise in the Columbia River, a flood stage was reached during July, 1918, at only one station, Brunswick, Mo., on the Grand River, and this was caused by backwater from the Missouri River; no damage was done.

THE ANNUAL RISE IN THE COLUMBIA RIVER.

The annual rise in the Columbia River began about one month later than usual and continued only about half the average length of time. The beginning of the flood at Portland, Oreg., June 12, was 4 days later in the season than flood stage has been reached previously during the 38 years of record. Only moderate flood stages were reached.

Warnings were issued in ample time to enable endangered property to be guarded against loss. Estimated loss along the rivers is as follows: Buildings, including factories, bridges, etc., $4,000; crops, $400; live stock, $8,000; suspension of business, $1,500.

TABLE 1.—*Flood stages in the Mississippi River drainage during July, 1918.*

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
Missouri:	*Feet.*			*Feet.*	
Blair, Nebr.	16			14.9	1–2
Grand:					
Brunswick, Mo.	10	1	4	10.2	2
Illinois:					
Beardstown, Ill.	12			11.8	13–14

TABLE 2.—*Annual rise in the Columbia River, 1918.*

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
Columbia River:	*Feet.*			*Feet.*	
Marcus, Wash.	24	*12	*23	31.2	*25–27
Wenatchee, Wash.	40	*23	*27	40.5	*24–26
Vancouver, Wash.	15	*12	†8	20.1	*26
Kootenai River:					
Bonners Ferry, Idaho	26	*15	*17	26.6	*16
Pen d'Oreille River:					
Newport, Wash.	16	*18	*28	17.0	*15–18
Willamette River:					
Portland, Oreg.	15	*12	†7	19.2	*25–27

*June. †July.

MEAN LAKE LEVELS DURING JULY, 1918.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., Aug. 5, 1918.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.*			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during July, 1918:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.26	581.92	572.58	246.85
Above or below—				
Mean stage of June, 1918	+0.16	−0.05	+0.05	−0.16
Mean stage of July, 1917	−0.34	±0.00	−1.27	−0.61
Average stage for July, last 10 years	−0.20	−1.05	−0.27	−0.09
Highest recorded July stage	−1.56	−1.66	−1.83	−1.87
Lowest recorded July stage	+0.78	+2.02	+1.12	+2.26
Average relation of the July level to—				
June level	+0.2	+0.1	−0.1	−0.1
August level	−0.2	±0.0	+0.2	+0.3

*Lake St. Clair's level: In July, 575.98 feet.

SECTION V.—SEISMOLOGY.

SEISMOLOGICAL REPORTS FOR JULY, 1918.

W. J. HUMPHREYS, Professor in Charge.

[Dated: Seismological Investigations, Weather Bureau, Sept. 3, 1918.]

TABLE I.—*Noninstrumental earthquake reports, July, 1918.*

Day.	Approximate time, Greenwich Civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		CALIFORNIA.								
1918.	*H. m.*		° ′	° ′			*M. s.*			
July 1	5 15	Salinas	36 41	121 39	2	2	02	None	Abrupt rocking NE–SW	Dr. M. A. Klein.
8	0 30?	Cahuilla	33 32	116 45	3	1	Few.	Rumbling	Gradual trembling N–S	Hartwell W. Gardner.
	1 20?	Hemet	33 44	116 58	4	1	03	Loud	Abrupt bumping E–W	C. E. McManigal.
	1 25?	Warner Springs	33 17	116 39	2-3	1	01	None	Abrupt rocking NE–SW	J. A. Ream.
10	5 24	Julian	33 04	116 36	2	1	08	Rumbling	Rapid rocking	J. H. L. Vogt.
12	17 20	Salinas	36 41	121 39	3	1	.....	None		Dr. E. D. Eddy.
15	0 26	Big Bar (Trinity County)	40 44	123 18	2	3	06	Yes	Abrupt trembling	H. W. Brannan.
		Boulder Creek (Santa Cruz County).	37 08	122 07	4	1	.....	None		The Sunspot.
		Eureka	40 48	124 11	6	2	20	Yes	Like a rushing wind. Gradual trembling 6 seconds, interval 2 seconds, then rocking 12 seconds E–W. Buildings swayed. All pendulum clocks on N–S walls and many on E–W stopped.	James Jones, observer, U. S. Weather Bureau.
		Fort Bragg	39 25	123 47	3	1	.....	None		W. F. Fuller.
		Morgan Hill	37 08	121 38	4	1	.....	None		The Sunspot.
22	0 55	Eureka	40 48	124 11	3	1	01	None	A single surge W–E	Beryl Adams.
22	12 42	Rialto	34 06	117 22	1	1	01	None	Abrupt jar and trembling	J. B. Witte.
24	23 38	Calexico	32 41	115 30	3	1	01	Faint	Rumbling. Rapid bumping SE–NW.	H. M. Rouse.
26	2 54	Mount Wilson	34 13	118 04	3	1	02	Rumbling	Abrupt rocking N–S	Wendell P. Hoge.
27	21 40	Keeler	36 38	117 52	4	1	01	None	Abrupt trembling N–S	P. Hansen.
		MISSOURI.								
1	19 02	Hannibal	39 41	91 20	2	1	01	None	Gradual rocking	B. L. Waldron.

TABLE 2.—*Instrumental seismological reports, July, 1918.*

(Time used: Mean Greenwich, midnight to midnight. Nomenclature: International.)

[For significance of symbols see REVIEW for January, 1918, p. 34.]

Alaska. *Sitka. Magnetic Observatory.* U. S. Coast and Geodetic Survey. J. W. Green.

Lat., 57° 03′ 00″ N.; long., 135° 30′ 06″ W. Elevation, 15.2 meters.

Instruments: Two Bosch-Omori, 10 and 12 kg.

Instrumental constants: V / T_0: E 10 17; N 10 15

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 3	.....	e_E	7 15 27	8	.....	.....	.....	No distinct phases.
		e_N	7 15 33	9	.....	.....	.....	
		M_E	7 15 52	.....	10	.....	.....	
		M_N	7 29 18	20	.....	20	.....	
		F	8 11 ..	.....	.....	.....	.....	
8	.....	P_N	10 45 56	7	.....	.....	.....	Throughout the month there were frequent faint tremors on E, apparently microseismic. On N there was frequently a wavy motion which sometimes resembled a portion of a distant 'quake, though usually with irregular waves.
		P_E	10 46 00	5	.....	.....	.....	
		eL_N	11 06 15	35	.....	.....	.....	
		eL_E	11 07 55	30	.....	.....	.....	
		M_N	11 11 16	20	.....	20	.....	
		M_E	11 17 ..	26	10	.....	.....	
		F_E	11 23 ..	.....	.....	.....	.....	
		F_N	11 38 ..	18	.....	.....	.....	
15	.....	P_N	0 27 14	3	.....	.....	.....	
		P_E	0 27 16	4	.....	.....	.....	
		L_N	0 30 37	.....	.....	.....	.....	
		L_E	0 30 45	1	.....	.....	.....	
		M_E	0 31 30	15	30	.....	.....	
		M_N	0 31 52	18	.....	40	.....	
		C_E	0 33 ..	8	.....	.....	.....	
		C_N	0 37 ..	9	.....	.....	.....	
		F_E	0 59 ..	8	.....	.....	.....	
		F_N	1 00 ..	8	.....	.....	.....	
21	.....	e_N	6 39 11	12	.....	.....	.....	Very doubtful.
		F_N	7 09 ..	.....	.....	.....	.....	

Arizona. *Tucson. Magnetic Observatory.* U. S. Coast and Geodetic Survey. F. P. Ulrich.

Lat. 32° 14′ 48″ N., long., 110° 50′ 06″ W. Elevation, 769.6 meters.

Instruments: Two Bosch-Omori. 10 and 12 kg.

Instrumental constants: V / T_0: E 10 14; N 10 18

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.

(Report for July 1, 1918, not received.)

California. *Berkeley. University of California.*

Lat., 37° 52′ 16″ N.; long., 122° 15′ 37″ W. Elevation, 85.4 meters.

(See Bulletin of the Seismographic Stations, University of California.)

California. *Mount Hamilton. Lick Observatory.*

Lat., 37° 20′ 24″ N.; long., 121° 38′ 34″ W. Elevation, 1,281.7 meters.

(See Bulletin of the Seismographic Stations, University of California.)

TABLE 2.—*Instrumental seismological reports, July, 1918*—Continued.

California. *Point Loma. Raja Yoga College.* F. J. Dick.

Lat., 32° 43′ 03″ N.; long., 117° 15′ 10″ W. Elevation, 91.4 meters.

Instrument: Two-component, C. D. West seismoscope.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 7	.....	.....	.....	.....	200	200	.....	Tremors during 24 hours preceding 15h. on dates given.
10	.....	.....	.....	.....	200	300	.....	
12	.....	.....	.....	.....	200	200	.....	
14	.....	.....	.....	.....	100	100	.....	
15	.....	.....	.....	.....	100	100	.....	
19	.....	.....	.....	.....	100	100	.....	

California. *Santa Clara. University of Santa Clara.* J. S. Ricard, S. J.

Lat., 37° 26′ 36″ N.; long., 121° 57′ 03″ W. Elevation, 27.43 meters.

(See Record of the Seismographic Station, University of Santa Clara.)

Colorado. *Denver. Sacred Heart College.* Earthquake Station. A. W. Forstall, S. J.

Lat., 39° 40′ 36″ N.; long., 104° 56′ 54″ W. Elevation, 1,655 meters.

Instrument: Wiechert 80 kg., astatic, horizontal pendulum.

(No earthquake records were kept during the month of July, 1918.)

District of Columbia. *Washington. U. S. Weather Bureau.*

Lat., 38° 54′ 12″ N.; long., 77° 03′ 03″ W. Elevation, 21 meters.

Instrument: Marvin (vertical pendulum), undamped. Mechanical registration.

Instrumental constants.. V 110, T_0 6.4

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 1	.....	P?.....	6 20 42	.....	.....	.....	.....	
		S?.....	6 35 40	.....	.....	.....	.....	
		L.....	6 42 30	.....	.....	.....	.....	
		L.....	7 07 ..	.....	.....	.....	.....	
		L.....	7 25 ..	20	.....	.....	.....	
		to.....	7 40 ..	.....	.....	.....	.....	
		M.....	7 29 30	.....	.....	*200	.....	Amplitude small.
		F.....	8	.....	.....	.....	.....	
3	.....	P.....	7 11 10	.....	.....	.....	.....	
		S?.....	7 18 20	.....	.....	.....	.....	
		L.....	7 41 30	16	.....	.....	.....	
		L.....	7 48 ..	.....	.....	.....	.....	
		L.....	7 54 ..	24	.....	.....	.....	
		L.....	7 58 ..	20	.....	.....	.....	Nearly continuous and uniform long waves. No definite maximum. Many amplitudes of about 0.5 mm.
		to.....	9 20 ..	20	.....	.....	.....	
		F.....	9 30 ..	.....	.....	.....	.....	
8	.....	P?.....	10 33 09	.....	.....	.....	.....	
		P_{repl}?	10 41 48	.....	.....	.....	.....	
		S.....	10 47 22	.....	.....	.....	.....	
		L.....	11 14 ..	.....	.....	.....	.....	
		L.....	11 19 ..	40	.....	.....	.....	
		L.....	11 29 ..	24	.....	.....	.....	
		F.....	12 40 ..	.....	.....	.....	.....	
12	.....	e_N.....	21 21 04	.....	.....	.....	.....	
		F.....	21 30 ..	.....	.....	.....	.....	Does not show on E-W.
15	.....	P.....	0 30 09	.....	.....	.....	.....	
		S?.....	0 35 52	.....	.....	.....	.....	
		L?.....	0 39 25	.....	.....	.....	.....	
		M.....	0 43 33	.....	.....	*7,000	.....	
		F.....	1 40 ..	.....	.....	.....	.....	
16	.....	P.....	20 20 55	.....	.....	.....	.....	
		S?.....	20 25 18	.....	.....	.....	.....	
		F.....	20 40 ..	.....	.....	.....	.....	
21	.....	e.....	6 26 30	.....	.....	.....	.....	
		eL.....	6 40 20	.....	.....	.....	.....	
		L.....	7 05 ..	.....	.....	.....	.....	
		L.....	7 17 ..	20	.....	.....	.....	
		F.....	8 15 ..	.....	.....	.....	.....	
29	.....	e_E.....	17 09 30	.....	.....	.....	.....	
		F.....	17 40 ..	.....	.....	.....	.....	
31	.....	P.....	14 42 57	.....	.....	.....	.....	
		S.....	14 48 09	.....	.....	.....	.....	
		L?.....	14 52 35	16	.....	.....	.....	
		F.....	15 30 ..	.....	.....	.....	.....	

*Trace amplitude.

District of Columbia. *Washington. Georgetown University.* F. A. Tondorf, S. J.

Lat., 38° 54′ 25″ N.; long., 77° 04′ 24″ W. Elevation, 42.4 meters. Subsoil: Decayed diorite.

Instruments: Wiechert 200 kg. astatic horizontal pendulums, 80 kg. vertical.

Instrumental constants.... V, T_0, ϵ: E 165 5.4 0; N 143 5.2 0; Z *80 3.0 0*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 1	.....	e.....	6 29 37	.....	.....	.....	.....	Microseisms. F lost.
		L.....	7 25 ..	26	.....	.....	.....	
3	.....	e_N.....	7 11 10	.....	.....	.....	.....	Microseisms. No distinct main.
		e_E.....	7 11 13	.....	.....	.....	.....	
		$P_{N\,repl}$	7 13 24	.....	.....	.....	.....	
		$P_{E\,repl}$	7 13 38	.....	.....	.....	.....	
		e_E.....	7 14 35	.....	.....	.....	.....	
		e_N.....	7 14 42	.....	.....	.....	.....	
		S_E.....	7 23 28	.....	.....	.....	.....	
		S_N.....	7 23 30	.....	.....	.....	.....	
		eL_E...	7 43 06	17	.....	.....	.....	
		eL_N...	7 43 06	17	.....	.....	.....	
		F.....	9 20 ..	.....	.....	.....	.....	
8	.....	e.....	10 41 55	.....	.....	.....	.....	Microseisms.
		S.....	10 47 41	.....	.....	.....	.....	
		eL.....	11 09 24	21	.....	.....	.....	
		F.....	12 35 ..	.....	.....	.....	.....	
12	.....	e.....	21 20 19	.....	.....	.....	.....	Heavy microseisms.
		F.....	21 58 ..	.....	.....	.....	.....	
14	.....	e_N.....	18 35 52	.....	.....	.....	.....	Heavy microseisms. 'Quake does not show on E-W.
		F.....	18 46 ..	.....	.....	.....	.....	
15	.....	iP_E....	0 30 11	.....	.....	.....	.....	E-W component readings more reliable.
		ePN....	0 30 14	.....	.....	.....	.....	
		eS_E....	0 36 03	.....	.....	.....	.....	
		eS_N....	0 36 10	.....	.....	.....	.....	
		eL_E....	0 39 42	.....	.....	.....	.....	
		M_E.....	0 44 03	8	*1,240	.....	.....	
		M_N.....	0 44 03	10	.....	*1,950	.....	
		F.....	1 50 ..	.....	.....	.....	.....	
16	.....	e.....	20 21 27	.....	.....	.....	.....	Microseisms.
		eL?....	20 25 18	.....	.....	.....	.....	
		F.....	20 50 ..	.....	.....	.....	.....	
21	.....	e.....	6 30 15	.....	.....	.....	.....	
		S_N?...	6 40 13	.....	.....	.....	.....	
		S_E?...	6 40 15	.....	.....	.....	.....	
		L.....	7 05 ..	20	.....	.....	.....	
		F.....	8 13 ..	.....	.....	.....	.....	
24	.....	e.....	11 35 21	.....	.....	.....	.....	Microseisms. Record lost after 12h. 31m. changing sheets.
		eL.....	11 46 24	.....	.....	.....	.....	
29	.....	L_N.....	17 52 ..	20ca	.....	.....	.....	Quake still going on.
		to.....	18 08 ..	.....	.....	.....	.....	
31	.....	eP.....	14 43 01	.....	.....	.....	.....	Heavy microseisms.
		S.....	14 48 19	.....	.....	.....	.....	
		eL_N...	14 53 06	15	.....	.....	.....	
		eL_E...	14 52 24	15	.....	.....	.....	
		F.....	? ? ?	.....	.....	.....	.....	

*Trace amplitude.

Kansas. *Lawrence. University of Kansas.* Department of Physics and Astronomy. F. E. Kester.

Lat., 38° 57′ 30″ N.; long., 95° 14′ 58″ W. Elevation, 301.1 meters.

Instrument: Wiechert.

Instrumental constants: V, T_0, ϵ: E 177 3.4 4:1; N 205 3.4 4:1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1918.			*H. m. s.*	*Sec.*	μ	μ	*km*	
July 15	.....	ePN....	0 23 14	.....	.....	.....	.....	E-W component was so illegible that only S and F could be distinguished.
		S.....	0 32 50	.....	.....	.....	.....	
		L_N?...	0 35 28	.....	.....	.....	.....	
		M_E?...	0 36 00	.....	.....	.....	.....	
		M_N?...	0 36 01	.....	.....	.....	.....	
		F.....	0 56 ..	.....	.....	.....	.....	

TABLE 2.—*Instrumental seismological reports, July, 1918*—Continued.

Maryland. *Cheltenham. Magnetic Observatory.* U. S. Coast and Geodetic Survey. George Hartnell.

Lat., 38° 44′ 00″ N.; long., 76° 50′ 30″ W. Elevation, 71.6 meters.

Instruments: Two Bosch-Omori, 10 and 12 kg.

Instrumental constants: {E V 10, T_0 15; N V 10, T_0 15}

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 3	.....	P_E	7 13 30	7	.....	.....	.....	
		P_N	7 13 31	6	.....	.....	.....	
		eS_N	7 30 21	10	.....	.....	.....	
		eS_E	7 30 30	11	.....	.....	.....	
		eL_N	7 55 45	25	.....	.....	.....	
		eL_E	7 56 16	25	.....	.....	.....	
		M_N	8 06 22	19	.....	30	.....	
		M_E	8 19 36	17	30	.....	.....	
		C_E	8 26 ..	16	.....	.....	.....	
		C_N	8 26 ..	17	.....	.....	.....	
		F_E	9 09 ..	17	.....	.....	.....	
		F_N	9 16 ..	18	.....	.....	.....	
8	.....	P_E	10 41 46	3	.....	.....	.....	
		P_N	10 41 58	3	.....	.....	.....	
		S_E	10 ? ?	.....	.....	.....	.....	
		eS_N	10 52 35	.....	.....	.....	.....	
		eL_N	11 18 01	40	.....	.....	.....	
		eL_E	11 18 19	40	.....	.....	.....	
		M_E	11 21 39	40	30	.....	.....	
		M_N	11 33 34	40	.....	20	.....	
		C	11 46 ..	18	.....	.....	.....	
		F_E	? ? ?	.....	.....	.....	.....	
		F_N	12 05 ..	.....	.....	.....	.....	
17	.....	P_E	0 30 24	3	.....	.....	.....	
		P_N	0 30 29	3	.....	.....	.....	
		S_E	0 36 12	5	.....	.....	.....	
		S_N	0 36 17	5	.....	.....	.....	
		L_E	0 41 42	18	.....	.....	.....	
		eL_N	0 42 ..	20	.....	.....	.....	
		M_N	0 44 23	14	.....	270	.....	
		M_E	0 46 26	13	190	.....	.....	
		C	0 54 ..	10	.....	.....	.....	
		F	1 32 ..	.....	.....	.....	.....	
21	.....	eL_N	7 11 45	11	.....	.....	.....	Phases very indefinite.
		eL_E	7 12 49	20	.....	.....	.....	
		M_E	7 19 ..	18	50	.....	.....	
		M_N	7 21 ..	18	.....	10	.....	
		C_N	7 22 ..	16	.....	.....	.....	
		C_E	7 28 ..	17	.....	.....	.....	
		F_N	8 02 ..	.....	.....	.....	.....	
		F_E	8 04 ..	.....	.....	.....	.....	
31	.....	S_E	14 48 08	8	.....	.....	.....	Microseisms most of day
		S_N	14 48 12	7	.....	.....	.....	
		L_E	14 52 34	19	.....	.....	.....	
		L_N	14 52 43	21	.....	.....	.....	
		M_E	14 54 08	15	50	.....	.....	
		M_N	14 55 51	16	.....	60	.....	
		C_E	14 59 ..	13	.....	.....	.....	
		C_N	14 59 ..	14	.....	.....	.....	
		F_E	15 19 ..	.....	.....	.....	.....	
		F_N	15 12 ..	.....	.....	.....	.....	

Massachusetts. *Cambridge. Harvard University Seismographic Station.* J. B. Woodworth.

Lat., 42° 22′ 36″ N.; long., 71° 06′ 59″ W. Elevation, 5.4 meters. Foundation: Glacial sand over clay.

Instruments: Two Bosch-Omori 100 kg. horizontal pendulums (mechanical registration).

Instrumental constants: {E V 80, T_0 23, ε 0; N V 50, T_0 25, ε 4:1}

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 3	.....	*O*	7 ca ..	.....	.....	.....	13,000+	
		$P_{E\ repl}$	7 13 31	6	.....	.....	.....	
		$P_{N\ repl}$	7 14 26	.....	.....	.....	.....	
		e_E	7 14 33	6	.....	.....	.....	
		S_N	7 23 20	13	.....	.....	.....	
		S_E	7 23 32	6	.....	.....	.....	
		e_N	7 24 32	12	.....	.....	.....	
		e_E	7 31 32	24–36	.....	.....	.....	
		L_N	7 59 22	.....	.....	.....	.....	
		M_N	8 03 36	.....	.....	.....	.....	
		M_N	8 20 32	.....	.....	.....	.....	
		$L_{E\ repl}$	8 39 00	40	.....	.....	.....	
		$L_{E\ repl}$	8 42 ..	30	.....	.....	.....	
		$L_{N\ repl}$	8 44 ..	.....	.....	.....	.....	
		L_E	8 49 ..	20	.....	.....	.....	
		L_E	9 11 ..	15	.....	.....	.....	
		F	9 29 ..	.....	.....	.....	.....	

Massachusetts. *Cambridge. Harvard University Seismographic Station.*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 8	.....	*O*	*10 postea*	.....	.....	.....	13,000±	
		P_N?	10 32 27	.....	.....	.....	.....	
		P_E	10 35 04	4	.....	.....	.....	
		P_N?	10 37 27	.....	.....	.....	.....	
		i_N	10 41 00	4	.....	.....	.....	
		i_E	10 41 02	4	.....	.....	.....	
		S_N?	10 46 59	6	.....	.....	.....	
		S_E?	10 49 12	.....	.....	.....	.....	
		S_N	10 50 17	8	.....	.....	.....	
		e_N	10 55 26	17	.....	.....	.....	
		e_E	10 56 04	7	.....	.....	.....	
		eL_N	11 11 02	.....	.....	.....	.....	
		eL_E	11 11 24	60	.....	.....	.....	
		L_E	11 16 04	40	.....	.....	.....	
		L_N	11 16 35	.....	.....	.....	.....	
		L_E	11 19 14	30	.....	.....	.....	
		L_N	11 20 24	40	.....	.....	.....	
		L_E	11 22 42	20	.....	.....	.....	
		L_N	11 23 ..	.....	.....	.....	.....	
		M_N	11 24 26	.....	.....	.....	.....	
		L_E	11 28 14	30	.....	.....	.....	
		L_E	11 33 18	20	.....	.....	.....	
		L_E	11 40 09	15	.....	.....	.....	
		L_N	12 22 ..	20	.....	.....	.....	Possibly $L_{N\ repl}$.
		L_N	12 28 28	24	.....	.....	.....	
		L_E	12 29 02	20	.....	.....	.....	
		F	12 50 ..	.....	.....	.....	.....	
14	.....	*O*	*18 postea*	.....	.....	.....	.....	Not registered on East component.
		e_N	18 37 01	.....	.....	.....	.....	
		L	18 38 35	10	.....	.....	.....	
		to	18 40 37	.....	.....	.....	.....	
		F	18 43 ..	.....	.....	.....	.....	
15	.....	O_E	*0 22 29*	.....	.....	.....	4,280	Compare July 21, 1914, *O 22h 30m 43s, 4280.* Shide, *O 22h 31m 17s*, putting epicenter 46° N., 130° W.; Pulkova gave 50° N., 140°W.
		eP_E	0 30 15	2	.....	.....	(38° 31′)	
		P_N	0 30 31	.....	.....	.....	.....	
		S_E	0 36 18	8	.....	.....	.....	
		S_N	0 36 40	6	.....	.....	.....	
		S_{repl}	0 39 18	8	.....	.....	.....	
		$S_{repl\ 2}$	0 39 50	10–12	.....	.....	.....	
		eL_N	0 42 00	40	.....	.....	.....	
		M_E	0 44 13	.....	.....	.....	.....	
		M_N	0 45 00	18	.....	.....	.....	
		M_E	0 47 03	.....	*2,750	.....	.....	
		M_E	0 48 05	.....	*6,000	.....	.....	
		M_E	0 49 57	.....	.....	.....	.....	
		F	1 42 ..	.....	.....	.....	.....	
21	.....	*O*?	*6 15 ca*	.....	.....	.....	12,400?	eL_E— eP_{repl} = 37m. 49s. Ladrone Islands? or between Formosa and Great Liu Kiu Island??
		eP_{repl}	6 30 32	4	.....	.....	(111°36′ ?)	
		i_E	6 40 15	6	.....	.....	.....	
		eL_E	7 08 21	48	.....	.....	.....	
		L_N	7 11 15	25	.....	.....	.....	
		M_E?	7 14 43	20	.....	.....	.....	
		L	7 23 21	16	.....	.....	.....	Beautiful sinusoidal record sets in.
		to	7 51 37	.....	.....	.....	.....	
		L_{repl}	8 04 ..	16	.....	.....	.....	
		L_E	8 23 50	16	.....	.....	.....	Very faint L waves on N undamped.
		F	8 32 ..	.....	.....	.....	.....	
24	.....	*O*	*11 postea*	.....	.....	.....	.....	P and S masked by microseisms.
		e?	11 35 46	.....	.....	.....	.....	
		e	11 42 01	14	.....	.....	.....	
		eL_N?	11 46 21	33–15	.....	.....	.....	
		L_N	11 54 54	20	.....	.....	.....	
		L_E	11 58 55	20	.....	.....	.....	
		to	12 01 ..	16	.....	.....	.....	Damped by magnet. F lost in changing records at 12h. 35m.
		L_N	12 05 ..	.....	.....	.....	.....	
		F	12 ? ?	.....	.....	.....	.....	
29	.....	L_N	17 52 10	24	.....	.....	.....	Very distant. Amplitude very small. M uncertain.
		L_E	17 52 37	24	.....	.....	.....	
		L_E	18 01 52	20	.....	.....	.....	
		F?	18 06 26	.....	.....	.....	.....	
31	.....	*O*?	*14 27 04*	.....	.....	.....	6,450?	*O* from eL_N—e_E (assumed synchronous with S_N).
		e_N	14 44 27	.....	.....	.....	.....	
		e_E	14 45 01	6	.....	.....	.....	
		i_N	14 48 49	6	.....	.....	.....	
		i_E	14 52 02	6	.....	.....	.....	
		eL_N	14 55 21	28	.....	.....	.....	N undamped.
		eL_E	14 55 48	20	.....	.....	.....	E damped by magnet.
		M_N	14 59 15	17	.....	.....	.....	
		L_E	15 01 47	15	.....	.....	.....	
		L_E	15 22 59	20	.....	.....	.....	
		F_E	15 28 30?	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental seismological reports, July, 1918*—Continued.

Missouri. *Saint Louis. St. Louis University.* Geophysical Observatory. J. B. Goesse, S. J.

Lat., 38° 38′ 15″ N.; long., 90° 13′ 58″ W. Elevation, 160.4 meters. Foundation: 12 feet of tough clay over limestone of Mississippi system, about 300 feet thick.

Instrument: Wiechert 80 kg. astatic, horizontal pendulum.

Instrumental constants.. V 80, T_0 7, ε 5:1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 3	.....	eL_N	7 20 ..	.....	.....	.....	.....	P and S not visible on record. Not registered on E-W.
		L_N	7 50 ..	.....	.....	.....	.....	
		M_N	7 55 ..	24	.....	*2,000	.....	
		F	8 32 ..	.....	.....	.....	.....	
8	.....	eP_N	10 41 54	.....	.....	.....	?	
		i_E	10 42 54	.....	.....	.....	.....	
		S_N?	10 51 06	.....	.....	.....	.....	
		L_N	11 07 12	18	.....	.....	.....	
		eL_E	11 20 30	.....	.....	.....	.....	
		L_N	11 22 ..	48	.....	.....	.....	
		L_E	11 23 12	.....	.....	.....	.....	
		L_N	11 25 06	36	.....	.....	.....	
		L_N	11 27 12	24	.....	.....	.....	
		L_E	11 33 06	.....	.....	.....	.....	
		F	11 56 ..	.....	.....	.....	.....	
15	.....	iP_N	0 28 42	.....	.....	.....	3,000	
		iP_E	0 28 45	.....	.....	.....	.....	
		iS_N	0 33 30	.....	.....	.....	.....	
		eL_N	0 35 00	6	.....	.....	.....	
		eL_E	0 39 06	.....	.....	.....	.....	
		M_N	0 39 12	15	.....	*8,000	.....	
		F	1 38 ..	.....	.....	.....	.....	
21	.....	eP_N	6 29 30?	.....	.....	.....	9,100?	Not registered on E-W.
		S_N	6 ? ?	.....	.....	.....	.....	
		eL_N	6 55 ..	.....	.....	.....	.....	
		L_N	7 05 12	.....	.....	.....	.....	
		M_N	7 16 ..	.....	.....	.....	.....	
		to	7 19 ..	18	.....	*1,000	.....	
		F	8 23 ..	.....	.....	.....	.....	

* Trace amplitude.

New York. *Buffalo. Canisius College.* John A. Curtin, S. J.

Lat., 42° 53′ 02″ N.; long., 78° 52′ 40″ W. Elevation, 190.5 meters.

Instrument: Wiechert 80 kg. horizontal.

Instrumental constants.. V 80, T_0 7, ε 5:1

(Report for July, 1918, not received.)

New York. *Fordham. Fordham University.* Daniel H. Sullivan, S. J

Lat., 40° 51′ 47″ N.; long., 73° 53′ 08″ W. Elevation, 29.3 meters.

Instrument: Wiechert, 80 kg.

Instrumental constants: V E 72, N 72; T_0 5.0; ε 0

(Report for July, 1918, not received.)

New York. *Ithaca. Cornell University.* Heinrich Ries.

Lat., 42° 26′ 58″ N.; long., 76° 29′ 09″ W. Elevation, 242.6 meters.

Instruments: Two Bosch-Omori, 25 kg., horizontal pendulums (mechanical registration).

Instrumental constants: V E 13, N 14; T_0 22, 25; ε 4:1, 4:1

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. Ao	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 3	.....	eP_E	7 13 16	4	.....	.....	.....	
		eP_N	7 14 36	4	.....	.....	.....	
		e_E	7 23 16	9	.....	.....	.....	
		e_N	7 24 58	11	.....	.....	.....	
		e_N	7 30 24	9	.....	.....	.....	
		e_E	7 30 27	12	.....	.....	.....	
		e_N	7 35 48	9	.....	.....	.....	
		eL_E	7 48 50	40	.....	.....	.....	
		eL_N	7 49 32	24	.....	.....	.....	
		F_N	9 17 ..	.....	.....	.....	.....	
		F_E	9 23 ..	.....	.....	.....	.....	
8	.....	eP_N	10 41 17	3	.....	.....	.....	
		e_E	10 49 04	5	.....	.....	.....	
		e_N	10 50 52	5	.....	.....	.....	
		e_N	10 57 12	7	.....	.....	.....	
		e_E	10 57 18	13	.....	.....	.....	
		L_E	11 10 14	40	.....	.....	.....	
		eL_N	11 17 37	38	.....	.....	.....	
		F_E	12 35 ..	.....	.....	.....	.....	
		F_N	12 37 ..	.....	.....	.....	.....	
	.....	.....	.....	.....	.....	.....	.....	Seismograph not in operation from July 13, 1h 45m to July 15, 22h 10m.
21	.....	e_N	6 46 37	7	.....	.....	.....	
		e_E	6 46 38	14	.....	.....	.....	
		eL_N	7 03 41	30	.....	.....	.....	
		eL_E	7 07 22	28	.....	.....	.....	
		F_N	8 18 ..	.....	.....	.....	.....	
		F_E	8 22 ..	.....	.....	.....	.....	
31	.....	P_N	14 43 23	3	.....	.....	.....	Time mechanism out of order.
		eP_E	14 44 37	4	.....	.....	.....	
		eS_N	14 48 35	6	.....	.....	.....	
		eS_E	14 50 23	9	.....	.....	.....	
		L_E	14 54 09	20	.....	.....	.....	
		L_N	14 54 32	26	.....	.....	.....	
		F_E	15 19 ..	.....	.....	.....	.....	
		F_N	15 22 ..	.....	.....	.....	.....	

Panama Canal. *Balboa Heights.* Governor, Panama Canal.

Lat., 8° 57′ 39″ N.; long., 79° 33′ 29″ W. Elevation, 27.6 meters.

Instruments: Two Bosch-Omori, 100 kg.

Intrumental constants.. V 35, T_0 20

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 8	.....	P	10 41 50	20	.....	.....	.....	Very slight tremors.
		F	10 53 16	.....	.....	.....	.....	
17	.....	P_N	15 39 14	.....	.....	.....	.....	2 disturbances reported from Chitre, Panama.
		P_E	15 39 21	.....	.....	.....	.....	
		L_N	15 39 28	20	.....	*1,500	.....	Time of M also.
		L_E	15 39 34	20	*2,000	.....	.....	Do.
		F_E	15 40 27	.....	.....	.....	.....	
		F_N	15 40 28	.....	.....	.....	.....	
19	.....	P	21 28 51	.....	.....	.....	265	Direction uncertain.
		L_E	21 29 31	20	.....	.....	.....	
		L_N	21 29 34	20	.....	.....	.....	
		M	21 29 42	.....	*1,000	*1,000	.....	
		F_N	21 34 11	.....	.....	.....	.....	
		F_E	21 34 16	.....	.....	.....	.....	
28	.....	P	20 58 32	.....	.....	.....	370	Do.
		L_E	20 59 14	20	.....	.....	.....	
		L_N	20 59 18	20	.....	.....	.....	
		M_N	20 59 24	.....	.....	*2,500	.....	
		M_E	20 59 32	.....	*1,500	.....	.....	
		F_E	21 05 04	.....	.....	.....	.....	
		F_N	21 06 00	.....	.....	.....	.....	
31	.....	P_E	14 39 16	.....	.....	.....	1,160	Do.
		P_N	14 39 23	.....	.....	.....	.....	
		L_N	14 41 27	20	.....	.....	.....	
		L_E	14 41 28	20	.....	.....	.....	
		M_N	14 42 16	.....	.....	*2,500	.....	
		M_E	14 42 42	.....	*2,000	.....	.....	
		F_N	14 56 14	.....	.....	.....	.....	
		F_E	14 56 54	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental seismological reports, July, 1918*—Continued.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
Porto Rico. *Vieques. Magnetic Observatory.* U. S. Coast and Geodetic Survey. F. L. Adams.								
Lat., 18° 09′ N.; long., 65° 27′ W. Elevation, 19.8 meters.								
Instruments: Two Bosch-Omori.								
Instrumental constants..				V: E 10, N 10	T_0: 17.6, 19.8			
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 3	.....	P_N.....	7 11 59	9	.....	.....	.....	May be the record of two 'quakes.
		P_E.....	7 12 21	10	.....	.....	.....	
		eL_E....	8 33 48	30	.....	.....	.....	
		L_N.....	8 ? ?	.....	.....	.....	.....	
		M_N.....	8 42 00	20	.....	10	.....	
		M_E.....	8 42 16	20	30	.....	.....	
		C_E.....	8 48 ..	20	.....	.....	.....	
		C_N.....	8 ? ?	.....	.....	.....	.....	
		F_E.....	9 04 ..	16	.....	.....	.....	
		F_N.....	9 07 ..	17	.....	.....	.....	
8	.....	P_N.....	10 45 01	5	.....	.....	.....	Nothing clear except the first appearance. Remainder very faint.
		P_E.....	10 45 12	5	.....	.....	.....	
		F.....	10 52 ..	.....	.....	.....	.....	
31	.....	P_E.....	14 41 26	7	.....	.....	.....	
		eP_N....	14 41 38	7	.....	.....	.....	
		eS_E....	14 46 09	.....	.....	.....	.....	
		S_N.....	14 ? ?	.....	.....	.....	.....	
		L_E.....	14 48 06	22	.....	.....	.....	
		L_N.....	14 ? ?	.....	.....	.....	.....	
		eM_N....	14 52 53	12	.....	10	.....	
		M_E.....	14 54 10	15	20	.....	.....	
		C_E.....	14 57 ..	16	.....	.....	.....	
		C_N.....	14 ? ?	.....	.....	.....	.....	
		F_E.....	15 02 ..	14	.....	.....	.....	
		F_N.....	15 02 ..	.....	.....	.....	.....	
Vermont. *Northfield. U. S. Weather Bureau.* Wm. A. Shaw.								
Lat., 44° 10′ N.; long., 72° 41′ W. Elevation, 256 meters.								
Instruments: Two Bosch-Omori, mechanical registration.								
Instrumental constants..				V: E 10, N 10	T_0: 15, 16			
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 3	.....	P_E?....	7 10 20	.....	.....	.....	.....	N-S component of small amplitude.
		S_E?....	7 17 45	.....	.....	.....	.....	
		eL_E....	7 48 ..	.....	.....	.....	.....	
		L_E.....	7 57 ..	26	.....	.....	.....	
		L_E.....	8 01 ..	20 ..	.....	.....	.....	
		to	8 13 ..	to 18	.....	.....	.....	
		L_E.....	8 45 ..	24	.....	.....	.....	
		F_E.....	9	.....	.....	.....	.....	
8	.....	e_N.....	10 46 10	.....	.....	.....	.....	
		eL_E....	11 09 ..	.....	.....	.....	.....	
		F.....	11 15 ..	.....	.....	.....	.....	
15	.....	P?.....	0 30 03	.....	.....	.....	.....	
		S?.....	0 36 11	.....	.....	.....	.....	
		eL.....	0 42 30	.....	.....	.....	.....	
		M.....	0 47 30	.....	*3,500	.....	.....	
		F.....	1 20 ..	.....	.....	.....	.....	
21	.....	eL.....	7 13 ..	24	.....	.....	.....	
		L.....	7 25 ..	16	.....	.....	.....	
		F.....	7 50 ..	.....	.....	.....	.....	
31	.....	e_N.....	14 45 ..	.....	.....	.....	.....	E-W component not recording.
		S_N?....	14 49 45	.....	.....	.....	.....	
		L_N.....	14 56 40	24	.....	.....	.....	
		F_N.....	15 10 ..	.....	.....	.....	.....	

* Trace amplitude.

Canada. *Ottawa. Dominion Astronomical Observatory.* Earthquake Station. Otto Klotz.†

Lat., 45° 23′ 38″ N.; long., 75° 42′ 57″ W. Elevation, 83 meters.

Instruments: Two Bosch photographic horizontal pendulums, one Spindler & Hoyer 80k. vertical seismograph.

Instrumental constants.. V: 120; T_0: 26

1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 1	.....	i.....	6 29 00	4	.....	.....	.....	F lost in wind tremors.
		e_N.....	6 38 54	.....	.....	.....	.....	
		eL_E?..	7 09 ..	.....	.....	.....	.....	
		L.....	7 25 ..	20	.....	.....	.....	
		L.....	7 37 ..	16	.....	.....	.....	
		F.....	? ? ?	.....	.....	.....	.....	
3	.....	P_{repl}..	7 13 00	4	.....	.....	12,000	Appears to be the confused record of several shocks.
		e_N.....	7 20 ..	8	.....	.....	.....	
		e_E.....	7 22 54	8	.....	.....	.....	
		e.....	7 25 12	12	.....	.....	.....	
		e.....	7 30 ..	12	.....	.....	.....	
		eL?...	7 45 ..	.....	.....	.....	.....	
		L.....	7 53 ..	20	.....	.....	.....	

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
Canada. *Ottawa. Dominion Astronomical Observatory*—Continued.								
1918.			*H. m. s.*	*Sec.*	μ	μ	*km.*	
July 3	.....	L.....	7 59 ..	22	.....	.....	.....	
		L.....	8 05 ..	18	.....	.....	.....	
		L.....	8 10 ..	18	.....	.....	.....	
		L.....	8 15 ..	17	.....	.....	.....	
		L.....	8 33 ..	17	.....	.....	.....	
		L.....	8 50 ..	20	.....	.....	.....	
		L.....	9 03 ..	17	.....	.....	.....	
		L.....	9 11 ..	17	.....	.....	.....	
		L.....	9 21 ..	15	.....	.....	.....	
		L.....	9 32 ..	15	.....	.....	.....	
		F.....	10	.....	.....	.....	.....	
8	.....	*O?*....	*10 24 ca*	.....	.....	.....	9,420?	F lost changing sheets at 12h 10m.
		iP_N?..	10 36 37	.....	.....	.....	.....	
		i_N.....	10 40 ..	.....	.....	.....	.....	
		P_{repl}?.	10 41 06	.....	.....	.....	.....	
		iS?....	10 47 08	.....	.....	.....	.....	
		i.....	10 56 30	.....	.....	.....	.....	
		eL.....	11 07 ..	45	.....	.....	.....	
		L.....	11 16 ..	34	.....	.....	.....	
		L.....	11 30 ..	22	.....	.....	.....	
		L.....	11 40 ..	16	.....	.....	.....	
		F.....	12 ? ?	.....	.....	.....	.....	
12	.....	e.....	21 22 42	.....	.....	.....	.....	
		eL.....	21 23 12	10	.....	.....	.....	
		L.....	21 30 ..	10	.....	.....	.....	
		e_E.....	21 51 ..	.....	.....	.....	.....	
		F.....	22	.....	.....	.....	.....	
14	.....	e.....	18 36 04	4	.....	.....	.....	
		e.....	18 37 ..	10	.....	.....	.....	
		to	18 41 ..	6	.....	.....	.....	
		e_N.....	18 54 ..	6	.....	.....	.....	
		to	18 59 ..	6	.....	.....	.....	
		F.....	.. .. ..	.....	.....	.....	.....	
15	.....	*O*.....	*0 22 55*	.....	.....	.....	3,860	
		iP.....	0 30 03	.....	.....	.....	.....	
		iS.....	0 35 42	.....	.....	.....	.....	
		eL.....	0 39 ..	.....	.....	.....	.....	
		M.....	0 44 ..	15	50	425	.....	
		L.....	0 51 ..	8	.....	.....	.....	
		L.....	1 05 ..	9	.....	.....	.....	
		L.....	1 15 ..	8	.....	.....	.....	
		L.....	1 29 ..	9	.....	.....	.....	
		L.....	1 55 ..	7	.....	.....	.....	
		L.....	2 05 ..	8	.....	.....	.....	
		F.....	2 35 ..	.....	.....	.....	.....	

SASKATOON RECORD.

		O.....	*0 22 56*	.....	.....	.....	1,910	
		iP.....	0 26 59	.....	.....	.....	.....	
		iS.....	0 30 14	.....	.....	.....	.....	
		eL.....	0 31 24	.....	.....	.....	.....	
16	.....	e.....	20 15 06	6	.....	.....	.....	
		e.....	20 17 36	6	.....	.....	.....	
		eL?....	20 24 24	6	.....	.....	.....	
		L?.....	20 29 06	.....	.....	.....	.....	
		F.....	20 45 ..	.....	.....	.....	.....	
21	.....	*O*?....	*6 18 10*	.....	.....	.....	8,640?	
		P?.....	6 30 04	.....	.....	.....	.....	
		S_N?....	6 39 56	.....	.....	.....	.....	
		eL.....	6 55 ..	.....	.....	.....	.....	
		L.....	7 03 ..	30	.....	.....	.....	
		L.....	7 14 ..	20	.....	.....	.....	
		L.....	7 25 ..	16	.....	.....	.....	
		L.....	7 41 ..	15	.....	.....	.....	
		L.....	8 00 ..	15	.....	.....	.....	
		F.....	8 20 ..	.....	.....	.....	.....	
21	.....	eL.....	10 46 ..	.....	.....	.....	.....	
		to	11 10 ..	18	.....	.....	.....	
23	.....	eL.....	14 25 ..	21	.....	*	.....	F lost in changing sheets.
		F.....	.. .. ..	.....	.....	.....	.....	
24	.....	eL_N?..	11 45 ..	.....	.....	.....	.....	
		L.....	11 56 ..	18	.....	.....	.....	
		L.....	12 03 ..	17	.....	.....	.....	
		L.....	12 07 ..	16	.....	.....	.....	
		F.....	12 20 ..	.....	.....	.....	.....	
25	.....	eL.....	21 45 ..	.....	.....	.....	.....	
		to	22	.....	.....	.....	.....	
29	.....	eL.....	12 21 ..	.....	.....	.....	.....	Amplitude very small.
		to	12 30 ..	18	.....	.....	.....	
29	.....	eL?....	17 28 ..	.....	.....	.....	.....	May not be seismic. High wind.
		to	18 30 ..	.....	.....	.....	.....	
31	.....	*O*.....	*14 36 20*	.....	.....	.....	4,210	
		P.....	14 43 53	.....	.....	.....	.....	
		P_{repl}..	14 45 06	.....	.....	.....	.....	
		S.....	14 49 52	.....	.....	.....	.....	
		S_{repl}..	14 52 ..	.....	.....	.....	.....	
		eL.....	14 54 36	24	.....	.....	.....	
		L.....	14 58 ..	21	.....	.....	.....	
		L.....	15 06 ..	11	.....	.....	.....	
		F.....	15 40 ..	.....	.....	.....	.....	

TABLE 2.—*Instrumental seismological reports, July, 1918*—Continued.

Canada. *Toronto. Dominion Meteorological Service.*

Lat., 43° 40′ 01″ N.; long., 79° 23′ 54″ W. Elevation, 113.7 meters. Subsoil: Sand and clay.

Instrument: Milne horizontal pendulum, North. In the meridian.

Instrumental constant.. T_0 18. Pillar deviation: 1 mm. swing of boom=0.50″.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
			H. m. s.	*Sec.*	μ	μ	*km.*	
1918. July 1	.....	L.....	7 02 48†	.....	.....	.....	.....	Microseisms going on.
		L.....	7 17 18	.....	.....	.....	.....	
		L.....	7 38 12	.....	*200	.....	.....	
		F.....	8 00 ..	.....	.....	.....	.....	
3	.....	P.....	7 14 30?	.....	.....	.....	.....	P not defined. Sudden deflection to east at 7h 30m 30s and then a momentary pause.
		P.....	7 16 54	.....	.....	.....	.....	
		S.....	7 21 54	.....	.....	.....	.....	
		S or iL	7 25 42	.....	.....	.....	.....	
		iL.....	7 30 30	.....	.....	.....	.....	
		L_E....	7 34 42	.....	.....	.....	.....	
		L.....	7 48 36	.....	.....	.....	.....	
		iL.....	7 58 30	.....	.....	.....	.....	
		M.....	8 04 18	.....	*4,300	.....	.....	
		iL.....	8 12 12	.....	.....	.....	.....	
		Repeat	.....	.....	.....	.....	.....	
		L.....	8 53 36	.....	.....	.....	.....	
		L_E....	8 57 30	.....	.....	.....	.....	
		M.....	9 00 00	.....	*1,500	.....	.....	
		L_E....	9 19 30	.....	.....	.....	.....	
		F.....	9 23 42	.....	.....	.....	.....	
8	.....	P.....	10 37 54?	.....	.....	.....	.....	P doubtful. May be a dual 'quake.
		S.....	10 48 36	.....	.....	.....	.....	
		iS.....	10 56 24	.....	.....	.....	.....	
		L.....	11 01 24	.....	.....	.....	.....	
		iL.....	11 14 54	.....	.....	.....	.....	
		M.....	11 35 36	.....	*1,000	.....	9,650?	
		L_E....	12 39 24	.....	.....	.....	.....	
		F.....	13 41 54	.....	.....	.....	.....	
14	.....	.....	.....	.....	.....	.....	.....	Microseisms after 17h.
15	.....	P.....	? ? ?	.....	.....	.....	.....	Microseisms. Eureka, Cal.?
		iS.....	0 35 00	.....	.....	.....	.....	
		iL.....	0 41 42	.....	.....	.....	.....	
		iL.....	0 44 12	.....	.....	.....	.....	
		M.....	0 44 54	.....	*2,400	.....	.....	
		F.....	1 46 42	.....	.....	.....	.....	
16	.....	L?.....	20 48 06?	.....	.....	.....	.....	
		L.....	20 50 36	.....	*50	.....	.....	
		F.....	20 56 48	.....	.....	.....	.....	
16	.....	L.....	23 55 18	.....	*50	.....	.....	
		F.....	23 59 12	.....	.....	.....	.....	
21	.....	P?.....	6 31 18?	.....	.....	.....	.....	Time doubtful. Clock stopped. Microseisms very numerous. Phases masked.
		S?.....	6 40 30	.....	.....	.....	.....	
		L.....	6 55 42	.....	.....	.....	.....	
		L.....	7 05 18	.....	.....	.....	.....	
		L.....	7 18 36	.....	.....	.....	.....	
		M.....	7 22 54	.....	*2,900	.....	.....	
		F.....	.....	.....	.....	.....	.....	
21	.....	M.....	11 01 54?	.....	*100	.....	.....	Do.
23	.....	S or L?	14 27 24	.....	.....	.....	.....	Phases masked by microseisms.
		L_E....	14 31 30	.....	.....	.....	.....	
		M.....	14 37 48	.....	*300	.....	.....	
		F?.....	14 50 36	.....	.....	.....	.....	
24	.....	L_E....	11 56 36	.....	.....	.....	.....	Do.
		M.....	11 59 42	.....	*200	.....	.....	
		F.....	.....	.....	.....	.....	.....	
25	.....	.....	.....	.....	.....	.....	.....	Microseisms when small 'quake was recorded at other stations. Also sheets 20th to 27th a mass of microseisms.
29	.....	.....	12	.....	.....	.....	.....	Microseisms when small 'quake was recorded at other stations.
29	.....	M.....	18 03 06	.....	*200	.....	.....	Microseisms mask phases.
31	.....	P?.....	14 48 36	.....	.....	.....	.....	Microseisms going on.
		S.....	14 53 42	.....	.....	.....	.....	
		L.....	14 57 12	.....	.....	.....	.....	
		M.....	15 00 06	.....	*1,000	.....	.....	
		F.....	.....	.....	.....	.....	.....	
31	.....	L.....	23 00 48?	.....	.....	.....	.....	Time doubtful. Microseisms mask phases.
		M.....	23 09 12?	.....	*100	.....	.....	
		F.....	.. .. ..?	.....	.....	.....	.....	

*Trace amplitude. †Original measurements given in tenths of minutes.

Canada. *Victoria, B. C. Dominion Meteorological Service.*

Lat., 48° 24′ N.; long., 123° 19′ W. Elevation, 67.7 meters. Subsoil: Rock.

Instrument: Wiechert, vertical: Milne horizontal pendulum, North. In the meridian

Instrumental constant.. T_0 18. Pillar deviation: 1 mm. swing of boom=0.54″.

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_O	Distance.	Remarks.
			H.m.s.	*Sec.*	μ	μ	*km.*	
1918. July 1	.....	P.....	6 32 00	.....	.....	.....	6,290	
		S.....	6 39 52	.....	.....	.....	.....	
		L.....	6 53 38	.....	.....	.....	.....	
		M.....	7 23 39	.....	*500	.....	.....	
		F.....	8 06 26	.....	.....	.....	.....	
3	.....	P.....	7 05 38	.....	.....	.....	9,000	Time of P determined from Vertical seismograph.
		S?.....	7 08 54	.....	.....	.....	.....	
		S.....	7 15 48	.....	.....	.....	.....	
		iS.....	7 17 28	.....	.....	.....	.....	
		L.....	7 36 22	.....	.....	.....	.....	Probably South America.
		M.....	7 47 47	.....	*4,000	.....	.....	
		Repeat	.....	.....	.....	.....	.....	
		L.....	8 56 41	.....	.....	.....	.....	
		iL.....	9 05 34	.....	.....	.....	.....	
		L_E....	9 10 04	.....	.....	.....	.....	
		L_E....	9 20 22	.....	.....	.....	.....	
		M.....	9 24 16	.....	*1,400	.....	.....	
		F.....	9 57 42	.....	.....	.....	.....	
				VERTICAL		*Az.*		
		P.....	*7 05 30*	*3*	.....	.....	.....	
		S.....	? ? ?	.....	.....	.....	.....	
		L.....	*7 36 00*	*18–24*	.....	.....	.....	
		M.....	*7 44 36*	*18*	.....	*7*	.....	
		F.....	? ? ?	.....	.....	.....	.....	
8	.....	P.....	10 46 14	.....	.....	.....	6,870	Northern Peru.
		S.....	10 54 36	.....	.....	.....	.....	
		L.....	11 08 12	.....	.....	.....	.....	
		M.....	11 26 05	.....	*1,700	.....	.....	
		F.....	12 58 02	.....	.....	.....	.....	
				VERTICAL		*Az*		
		P.....	*10 45 07*	*3*	.....	.....	*7,740*	*Northern Peru.*
		S.....	*10 54 13*	*6*	.....	.....	.....	
		L.....	? ? ?	*36*	.....	.....	.....	
		M.....	*11 28 43*	*30*	.....	*3*	.....	
		F.....	11 ? ?	.....	.....	.....	.....	
15	.....	P.....	0 25 25	.....	.....	.....	651	Northern California.
		S or L..	0 26 51	.....	.....	.....	.....	
		M.....	0 28 51	.....	*11,500	.....	.....	Felt at Eureka.
		F.....	1 19 50	.....	.....	.....	.....	
				VERTICAL.		*Az.*		
		P.....	*0 25 00*	*3*	.....	.....	*750*	
		S.....	*0 26 46*	*6*	.....	.....	.....	*Do.*
		L.....	*0 28 40*	*12–15*	.....	.....	.....	
		M.....	*0 29 18*	*10*	.....	*25*	.....	
		F.....	? ? ?	.....	.....	.....	.....	
16	.....	M.....	20 50 32	.....	*100	.....	.....	
16	.....	L.....	23 58 24?	.....	.....	.....	.....	
17	.....	M.....	0 02 51	.....	*200	.....	.....	
		F.....	0 06 47	.....	.....	.....	.....	
21	.....	P.....	6 33 26	.....	.....	.....	5,560	
		S.....	6 40 39	.....	.....	.....	.....	
		L.....	6 51 34	.....	.....	.....	.....	
		M.....	7 09 20	.....	*2,000	.....	.....	
		F.....	9 07 52	.....	.....	.....	.....	
21	.....	M.....	10 40 48	.....	*300	.....	.....	
23	.....	L.....	14 07 26?	.....	.....	.....	.....	
		M.....	14 18 15	.....	*300	.....	.....	
		F.....	14 36 27	.....	.....	.....	.....	
24	.....	L.....	11 37 34	.....	.....	.....	.....	
		M.....	11 51 20	.....	*200	.....	.....	
		F.....	12 15 56	.....	.....	.....	.....	
27	.....	.....	.....	.....	.....	.....	.....	Revelstoke reports a slight quake during night of 27-28.
29	.....	L.....	12 01 06	.....	.....	.....	.....	
		M.....	12 08 36	.....	*200	.....	.....	
		F.....	12 23 06	.....	.....	.....	.....	
29	.....	P.....	17 12 36	.....	.....	.....	10,900	
		S.....	17 24 13	.....	.....	.....	.....	
		L.....	17 44 53	.....	.....	.....	.....	
		M.....	17 59 08	.....	*500	.....	.....	
		F.....	18 04 34	.....	.....	.....	.....	
31	.....	S.....	15 01 49?	.....	.....	.....	.....	
		L.....	15 06 14	.....	.....	.....	.....	
		M.....	15 16 04	.....	*700	.....	.....	
		F.....	15 58 51	.....	.....	.....	.....	
31	.....	L.....	22 45 04	.....	.....	.....	.....	
		M.....	22 55 23	.....	*250	.....	.....	
		F.....	23 10 09	.....	.....	.....	.....	

* Trace amplitude.

TABLE 3.—*Late seismological reports (instrumental).*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
Arizona. *Tucson. Magnetic Observatory.* U. S. Coast and Geodetic Survey. F. P. Ulrich.								
Lat. 32° 14′ 48″ N.; long., 110° 50′ 06″ W. Elevation, 769.6 meters.								
Instruments: Two Bosch-Omori, 10 and 12 kg.								
Instrumental constants			V	T_0				
		E	10	14				
		N	10	18				
1918.			*H. m. s.*	*Sec.*	*μ*	*μ*	*km.*	
June 7	.....	P_E	21 31 02	5	.....	.....	.....	
		P_N	21 31 03	4	.....	.....	.....	
		eL_E	21 35 17	18	.....	.....	.....	
		eL_N	21 35 47	13	.....	.....	.....	
		M_E	21 37 01	13	1,230	.....	.....	
		M_N	21 37 42	13	.....	860	.....	
		C_E	21 40 ..	10	.....	.....	.....	
		C_N	21 40 ..	12	.....	.....	.....	
		F_N	22 00 ..	7	.....	.....	.....	
		F_E	22 06 ..	12	.....	.....	.....	
12	.....	P_E	4 28 44	4	.....	.....	.....	
		P_N	4 28 50	.....	.....	.....	.....	
		eL_E	4 33 56	.....	.....	.....	.....	
		eL_N	4 33 58	.....	.....	.....	.....	
		M	4 35 ..	10	10	10	.....	
		F_N	4 45 ..	.....	.....	.....	.....	
		F_E	4 58 ..	8	.....	.....	.....	
New York. *Ithaca. Cornell University.* Heinrich Ries.								
Lat., 42° 26′ 58″ N.; long., 76° 29′ 09″ W. Elevation, 242.6 meters.								
Instruments: Two Bosch-Omori, 25 kg., horizontal pendulums (mechanical registration).								
Instrumental constants			V	T_0	e			
		E	13	22	4:1			
		N	14	25	4:1			
1918.			*H. m. s.*	*Sec.*	*μ*	*μ*	*km.*	
June 1	.....	e_E	14 53 30	12	.....	.....	.....	
		F_E	15 58 ..	.....	.....	.....	.....	
3	.....	ePN	0 14 02	6	.....	.....	.....	
		eP_E	0 14 05	5	.....	.....	.....	
		S_N	0 23 00	5	.....	.....	.....	
		S_E	0 23 12	13	.....	.....	.....	
		L_N	0 30 18	30	.....	.....	.....	
		F_E	1 00 ..	.....	.....	.....	.....	
4	.....	e_E	17 40 00	13	.....	.....	.....	
		e_E	17 46 32	21	.....	.....	.....	
		L_E	18 04 08	38	.....	.....	.....	
		L_N	18 05 10	25	.....	.....	.....	
		F_E	18 57 ..	.....	.....	.....	.....	
7	.....	e_E	21 39 ..	.....	.....	.....	.....	Part of record lost changing sheets. Periods short.
		Y_E	22 29 ..	.....	.....	.....	.....	
11	.....	e_N	12 46 36	4	.....	.....	.....	
		e_E	12 46 41	5	.....	.....	.....	
		e_E	12 48 59	18	.....	.....	.....	
		e_N	12 49 37	12	.....	.....	.....	
		F_N	13 09 ..	.....	.....	.....	.....	
		F_E	13 15 ..	.....	.....	.....	.....	
12	.....	L_N	4 45 30	14	.....	.....	.....	
		F_N	5 02 ..	.....	.....	.....	.....	
13	.....	ePN	9 05 14	4	.....	.....	.....	
		eP_E	9 05 29	3	.....	.....	.....	
		eS_N	9 10 59	7	.....	.....	.....	
		eS_E	9 11 02	9	.....	.....	.....	
		F_E	9 19 ..	.....	.....	.....	.....	
		F_N	9 21 ..	.....	.....	.....	.....	
16	.....	P_N	12 33 57	3	.....	.....	.....	
		S_E	12 38 48	5	.....	.....	.....	
		S_N	12 38 49	4	.....	.....	.....	
		F_E	12 51 ..	.....	.....	.....	.....	
		F_N	12 52 ..	.....	.....	.....	.....	
17	.....	e_E	16 44 57	10	.....	.....	.....	
		e_N	16 45 02	7	.....	.....	.....	
		F_N	16 49 ..	.....	.....	.....	.....	
		F_E	16 50 ..	.....	.....	.....	.....	
22	.....	ePN	22 13 37	5	.....	.....	.....	
		eS_E	22 19 48	11	.....	.....	.....	
		L_E	22 23 54	22	.....	.....	.....	
		L_N	22 24 43	25	.....	.....	.....	
		F_N	22 35 ..	.....	.....	.....	.....	
		F_E	22 38 ..	.....	.....	.....	.....	

80205—18——3

SEISMOLOGICAL DISPATCHES.[1]

Panama, July 20, 1918.

Earthquake shocks have been felt 80 miles to the west of this city, causing some apprehension among the people of that region. No casualties occurred nor was any damage done. (Assoc. Pr.)

Johannesburg, South Africa, July 21, 1918.

Ten earth shocks occurred in this region yesterday. They caused the collapse of the mine works. Damage has not been ascertained as yet. (Assoc. Pr.)

[1] Reported by the organization indicated and collected by the seismological station at Georgetown University, Washington, D. C.

SECTION VI.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

C. FITZHUGH TALMAN, Professor in Charge of Library.

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Alvord, John W[atson] & Burdick, Charles B[aker].
Relief from floods; the fundamentals of flood prevention, flood protection, and the means for determining proper remedies. New York. 1918. viii, 175 p. illus. fold. map. charts. tables. 24 cm.

Blue Hill meteorological observatory.
Observations and investigations made . . . in the year 1917 under the direction of Alexander McAdie . . . Cambridge, Mass. 1918. tables. 30 cm. (Annals of the Astronomical observatory of Harvard College . . . vol. 83, pt. 2. p. [65]-92.)

Bouches-du-Rhône. Commission de météorologie.
Bulletin annuel . . . Année 1916=35e année. Marseille. 1917. xii, 68, xxiv, p. map. charts (part. fold.) tables. 28½ cm.

Cambridge university. Solar physics observatory.
Fourth annual report of the director of the Solar physics observatory to the Solar physics committee, 1916, April 1—1917, March 31. [Cambridge. 1917.] cover-title. [6] p. 28½ cm.
Fifth annual report of the director . . . 1917, April 1–1918, March 31. Cambridge. 1918. [4] p. 28 cm.

Cienfuegos. Observatorio del Colegio "Ntra. Sra. de Montserrat."
Anales. No. 7. Observaciones meteorológicas de 1917. Habana. 1918. 2 p. l., 7 p. tables. 34½ cm.

Denmark. Meteorologiske institut.
Magnetisk aarbog. Annuaire magnétique, 1916. Kjøbenhavn. 1918. 11 p. fold. charts. tables. 32½ cm. At head of title: Publikationer fra det Danske meteorologiske institut, ved C. Ryder, direktør. Aarbøger. In French.

Foote, Paul D.
Some characteristics of the Marvin pyrheliometer. Washington. 1918. p. l., 605–634 p. plate. charts. 9 tables. diagrs. 26 cm. At head of title: Department of commerce. Scientific papers of the Bureau of Standards . . . No. 323.

Great Britain. Meteorological office.
The marine observer's handbook. Second edition . . . London. 1918. iv, 142 p. front. illus. plates. charts. tables (part. fold.) 24½ cm. M. O. 218. (2d edition.)

Hongkong. Royal observatory.
Report of the director . . . for the year 1917. Hongkong. 1918. cover-title. 14 p. incl. tables. 14½ cm.

Howchin, Walter.
Notes on the remarkable hailstorm near Adelaide, on May 12, 1917. cover-title. illus. plate. 21 cm. (Reprinted from Transactions of the Royal society of South Australia, vol. 41, 1917.)

Hug, J.
Die Grundwasservorkommnisse der Schweiz. Bern. 1918. xvi, 168 p. plates. 5 fold. maps. charts (part fold.) tables. 31½ cm. At head of title: Schweizer. Department des Innern. Annalen der Schweizer. Landeshydrographie; herausgegeben unter der Leitung von Dr. Léon W. Collet, Direktor der Abteilung für Wasserwirtschaft. Band 3. "Planche 3 suivra après guerre."

Mexico. Instituto geologico.
La seismologia en Mexico hasta 1917, por Manuel Muñoz Lumbier. Mexico. 1918. 2 p. l, 102, [3] p. plates (part. col.) maps. fold. tables. fold. diagrs. 29½ cm. At head of title: Secretaria de industria, comercio y trabajo. Departmento de estudios y exploraciones geologicos. Boletin num. 36.

Miami conservancy district, Ohio.
Technical reports. Part 1 & 5. Dayton, O. 1917. 2 v. illus. maps. charts (part. fold.) tables. 23 cm. Part 1.—The Miami valley and the 1913 flood. Part 5.—Storm rainfall of eastern United States.

Modena. R. Università. Osservatorio geofisico.
Osservazioni meteorologiche fatte nell' Osservatorio geofisico della R. Università di Modena nell' annata 1912–1914. Modena. 1914–1917. 3 v. fold. charts. tables. 32 cm. (Publicazioni dell R. Osservatorio geofisico di Modena, No. 29–31.)

Negri, Galdino.
Tiempos y velocidades en los cálculos sismológicos. Publicado en la Revista del Centro estudiantes de ingenieria, número 189. Buenos Aires. 1918. 22 p., 1. incl. tables. 26 cm.

Rolf, Bruno.
Probabilité et pronostics des pluies d'été ... Upsala. 1917. vii, 25, [2] p. charts. tables. 28½ cm.

Ôsaka. Meteorological observatory.
Annual report for the year 1917. Part 2. Seismological observations in Ôsaka, 1917. Ôsaka. 1918. cover-title. 24, [40] p. 3 fold. charts. tables. 26 cm.

Pearson, S. K.
The weather man's business. illus. chart. 24 cm. (Excerpted from Guaranty news, N. Y. vol. 7, no. 6. August, 1918. p. 193–196.)

Stonyhurst college observatory.
Results of meteorological, magnetical, and seismological observations, 1917 ... Blackburn. 1918. xiv, 39 p. incl. tables. 18¼ cm.

Switzerland. Abteilung für Wasserwirtschaft.
Graphische Darstellungen der schweizerischen hydrometrischen Beobachtungen ... Tägliche Wassermengen an den Haupt-Pegelstationen ... Tableaux graphiques des observations hydrométriques suisses ... Débits quotidiens aux stations limnimétriques principales ... 1915. Bern. 1918. 44 p. fold. charts. tables. 38½ cm. At head of title: Schweizerischen Departement des Innern. Veröffentlichungen der Abteilung für Wasserwirtschaft, herausgegeben unter der Leitung von Dr. Léon W. Collet. [In French and German.]
Tabellarische Zusammenstellung der Hauptergebnisse der schweizerischen hydrometrischen Beobachtungen für das Jahr 1915 ... Table de récapitulation des principaux résultats des observations hydrométriques suisses pour l'année 1915 ... Bern. 1917. 79 p. incl. tables. 38½ cm. At head of title: Schweizerisches Departement des Innern. Veröffentlichungen der Abteilung für Wasserwirtschaft ... [In French and German.]

Uruguay. Instituto meteorológico nacional.
Datos del observatorio central, Montevideo. Rio de la Plata-Puerte de Montevideo. Año 1917. [Montevideo. 1918.] cover-title. 56 p. 32 cm.

Zomba. Observatory.
Summary of year's observations, 1917. [Zomba. 1918.] 14 p. 34 cm.

RECENT PAPERS BEARING ON METEOROLOGY AND SEISMOLOGY.

C. FITZHUGH TALMAN, Professor in Charge of Library.

The following titles have been selected from the contents of the periodicals and serials recently received in the library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

Franklin institute. Journal. Philadelphia. v. 186. August, 1918.
Humphreys, W[illiam] J[ackson]. Physics of the air. p. 211–232. (Continuation.)

Imperial earthquake investigation committee. Bulletin. Tokyo. v. 9. no. 1. 1918.
Omori, F[usakichi]. Note on the form of Japanese castle walls. p. 30–32.
Omori, F[usakichi]. Vibration of reinforced concrete chimneys. p. 1–29.

Meteorological society of Japan. Journal. Tokyo. 37th year. July, 1918.
Sekiguchi, R. Some correlations between the solar activity and the far eastern climates. [Abstract.] p. 33–42.
Nakamura, Saemontaro. Note on the distribution of the intensity of an earthquake. p. 43–47.

National academy of sciences. Proceedings. Baltimore. v. 4. July, 1918.
St. John, Ancel. The crystal structure of ice. p. 193–197.

Nature. London. v. 101. 1918.

Rayleigh [Lord]. Propagation of sound and light in an irregular atmosphere. p. 284. (June 13.)

Cave. C. J. P. The drift of meteor trails. p. 284. (June 13.)

Ward, Robert De C[ourcy]. The tornadoes of the United States. (July 18.) p. 395–399. [Abridged from Q. J. Roy, Met'l. Soc.]

Popular astronomy. Northfield. v. 26. June–July, 1918.

Barnard, E. E. The great aurora of 1918, March 7. p. 377–379.

Royal institution of Great Britain. Proceedings. London. v. 21. April, 1918.

Shaw, Napier. Illusions of the upper air. p. 603–624.

Science abstracts. London. v. 21. pt. 6. 1918.

Hellmann, G [ustav]. On severe winters. p. 251–252. [Abstract.]

Hess, V. F., & Schmidt, W. Distribution of radio-active gases in the open air. p. 267. [Abstract.]

Scientific American supplement. New York. v. 86. 1918. (August 24.)

The oceanographic work of the Royal Italian committee. p. 118–119. [Transl. from Larousse mensuel. Describes meteorological work of the committee.]

Scientific American supplement—Continued.

Stuhlmann, Otto. The aurora. Is it possible to explain it by means of a corpuscular ray theory? p. 132–134. (August 31.)

Symons's meteorological magazine. London. v. 53. June, 1918.

Bonacina, L. C. W. Inverse weather conditions. p. 51–52.

Mountain mists and water supply. p. 55.

Terrestrial magnetism. Baltimore. v. 23. June, 1918.

Mauchly, S. J. A study of pressure and temperature effects in earth-current measurements. p. 73–91.

Peters, W. J. Results of dip-of-horizon measurements made on the *Galilee* and *Carnegie*, 1907–1917. p. 47–60.

Western society of engineers. Journal. Chicago. v. 23. March, 1918.

Richards, Harry, Donoghue, George T., & Galligan, W. J. Snow removal. p. 175–191.

Académie des sciences. Comptes rendus. Paris. Tome 167. 22 juillet 1918.

Garrigou-Lagrange, Paul. Les movements généraux de l'atmosphère. p. 170–172.

SECTION VII.—THE WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF JULY, 1918.

P. C. DAY, Climatologist and Chief of Division.

[Dated: Climatological Division, Weather Bureau, July 3, 1918.]

PRESSURE AND WINDS.

The distribution of the mean atmospheric pressure over the United States and Canada and the prevailing direction of the winds for July, 1918, are graphically shown on Chart VII, while the means at the several stations, with the departures from the normal, are shown in Tables I and III.

The month opened with a storm central in the region of the Great Lakes, and with moderately high pressure prevailing in the middle and southern portions of the country between the Rocky and Appalachain Mountains and in the extreme eastern Canadian Provinces. Elsewhere atmospheric pressure was near the normal.

The pressure continued high in the south and the far eastern Canadian Provinces until about the middle of the first decade, and in the north it remained generally below the normal. During the latter half of the decade the conditions were nearly reversed, the pressure being above normal over much of the central and northern portions of the country while in the south it was usually slightly below the seasonal average. Pressure continued above the normal in the Central Valleys during much of the second decade, and was relatively low along the Atlantic coast and also in the far West until the latter part of the decade.

During the last decade of the month the pressure was nearly continuously above the normal over the northern and central districts to eastward of the Great Plains, while in the Rocky Mountain region and to the westward it was similarly below. The month closed with pressure above normal from the Great Lakes southwestward to the southern Rocky Mountain region, and low pressure was the rule along the Atlantic and Gulf coasts and over the far western districts.

For the month as a whole the pressure averages were above the normal throughout the entire country save over small areas in the Southeast and far Northwest. The region of greatest excess covered the northern and central districts from the Rocky Mountains to the Great Lakes.

The absence of marked pressure variations resulted in a month of light air movements, and no strong preponderence of winds from any particular direction was apparent, save in the Great Plains region, where they were mostly from southerly points. A few high winds were observed at exposed points along the immediate Pacific coast, where such winds are nearly constant, but elsewhere the month was notably free from winds of a destructive character.

TEMPERATURE.

At the beginning of July the weather was generally cool in the Lake region and central valleys, and rather warm in the mountain districts of the West. Temperatures somewhat above normal continued in the far West during most of the first decade, and in the central and eastern districts the weather continued cool. On the morning of the 3d, at points in the Middle and North Atlantic States, the temperature was as low as had been recorded previously in July, or lower, and on the following morning heavy frost occurred in the mountain districts of northern Wyoming. During the following few days the weather was unusually cool for the season in the region of the Great Lakes, but in the South high day temperature prevailed. Considerably cooler weather soon overspread the South Atlantic and East Gulf States and the decade closed with temperatures below the average generally from the Plains States eastward, especially in the central Appalachian Mountain district. During the next few days the temperature continued below the seasonal average east of the Rocky Mountains, except in the southern Plains States, and slightly above the normal to the westward. About the middle of the month warmer weather prevailed in the Atlantic Coast States and lower temperatures in the Northwest, while in Oklahoma and Texas the weather continued warmer. During the latter part of the second decade moderately cool weather prevailed in the region of the Great Lakes, but it was warmer in the Appalachian Mountains and over the Atlantic coast districts, and a rather marked rise in temperature occurred in the Central Plateau.

The early days of the third decade were marked by higher temperature in the central and northern districts from the Mississippi Valley eastward, but there was little change in the eastern districts during the succeeding few days. Much cooler weather moved in over the far Northwest, where the temperature fell to subnormal on the 24th. Toward the latter part of the decade cooler weather overspread the North Pacific coast, moved eastward to the Dakotas, and thence to the Lakes region by the end of the month. During this period temperature continued moderately high in the South, and it was generally above the normal in the far Southwest. The month closed with warmer weather in the far Northwest and extreme West, and with subnormal temperature generally east of the Rocky Mountains, especially from the Lakes region eastward, where some localities experienced the lowest July temperature of record, with light frost in exposed places in the extreme North.

As a whole July was warmer than normal in western New England and eastern New York, the central and southern portions of the Great Plains, in the western Gulf States, and generally in the far Northwest. From the Great Lakes southeastward to the Atlantic coast, and from the Dakotas southwestward to Arizona and southern California, the average temperature for the month was generally several degrees below the normal.

PRECIPITATION.

July opened with local showers in most districts from the Mississippi River eastward, with some heavy falls in the Lake region, but elsewhere fair weather prevailed. During the following few days heavy local rains occurred in southeastern Texas, and at a few points in the upper Mississippi Valley, and light showers occurred in Arizona and New Mexico. Toward the latter part of the first decade showers were general in the Ohio Valley and Tennessee and to the northeastward and southeastward, and in the central and northern districts from the Rocky Mountains westward. Early in the second decade much needed rain fell over the Atlantic Coast States from the Carolinas northward, also in the central and east Gulf States, and local showers were reported from many points in the Great Plains region and thence westward to the Plateau States. About the middle of the month rain was quite general in the upper Mississippi Valley and western Lake region, and also in the central Plains and portions of the Rocky Mountains section. During the latter part of the decade showers occurred in many districts from the Mississippi Valley eastward, the

amounts being rather generous over the east Gulf and South Atlantic States. During the early days of the third decade showers continued in the Southeast, and local rains occurred in the upper Lakes region, upper Mississippi Valley and northern and central Plains States, and at points in the Rocky Mountains and far Southwest. Toward the middle of the decade showers occurred in the South Atlantic States, from the lower Missouri Valley northeastward to the lower Lakes, and from North Dakota westward. From about the 26th to the 28th there was precipitation at many points east of the Mississippi River, and rain was quite general in the northern districts from the upper Mississippi Valley westward to the Pacific, the falls being generous in many localities and heavy in portions of Iowa and the Ohio Valley. Showers occurred during the last few days of the month in most localities from the central and southern Mississippi Valley eastward and northeastward, and light local rains occurred in the Plains regions and in Arizona and New Mexico.

For the month as a whole the precipitation was heavy over the eastern Florida Peninsula and generally along the Atlantic coast northward to North Carolina, and moderate to fairly heavy in most other sections east of the Rocky Mountains, except in the central Mississippi Valley and to the southwest and in portions of Virginia, Maryland, and the Lake region, where it was light. West of the Rocky Mountains the precipitation was also generally light, while considerable areas in California, Nevada, and Texas received no rain during the month.

RELATIVE HUMIDITY.

The humidity was relatively low from the upper Mississippi Valley and Middle and Southern Plains region eastward to the Atlantic coast, except over the extreme northeastern States. In the Southern Plains the humidity was notably low, and hot, drying winds were of frequent occurrence. The relative humidity was high in South Dakota, and it was generally above normal in the Rocky Mountain and Plateau districts and along the immediate Pacific coast.

GENERAL SUMMARY.

For July as a whole farm work progressed favorably in most sections. The harvesting of wheat and other small winter grains was very generally completed, and thrashing made good progress. Haying operations and the cultivation of corn and cotton were pursued without material hinderance. The weather was too cool in much of the east and northeast for the best growth of some crops and there was a decided lack of moisture in many sections during the entire month. Corn made fairly good progress in most districts during the first half of the month, although it was rather dry in some sections and cool in others. During the latter half the crop was unfavorably affected by lack of moisture in most States west of the Mississippi River, and in portions of Missouri, Kansas, Oklahoma, Arkansas, and Texas, much damage resulted. Elsewhere fair to good progress was made.

Cotton progressed favorably during the first decade of the month, and thereafter the growth was fair to good in the East, but high temperatures and dry weather west of the Mississippi River were unfavorable for the development of the crop. Spring wheat made good progress in most sections, but from central North Dakota westward the crop suffered from lack of moisture. Other grain crops made satisfactory development in most districts. The weather was generally favorable for potatoes over nothern and eastern districts, and truck crops, pastures, meadows, and fruit made generally satisfactory progress, although apples were reported as only fair to poor in parts of the central Appalachian region and the central Mississippi Valley.

SEVERE LOCAL STORMS.

The following notes of severe storms have been extracted from the official reports of the various States:

Indiana.—On July 28, 1918, about 4:15 p. m., a severe storm somewhat resembling a tornado occurred in a portion of the city of Terre Haute. The path of destruction was about one-third of a mile wide and nearly a mile long. Several small houses and other buildings were more or less demolished or partly unroofed, many trees broken off, and telegraph and other wires blown down. Estimated damage, $10,000.

North Carolina.—On July 12, 1918, very heavy hail damaged or destroyed crops at Holly Springs, Wake County, over an area 4 miles wide and 8 miles long. Hail fell to a depth of 6 inches for a width of 2 miles; within this area crops were completely destroyed, but only about one-fourth of the area was under cultivation. Some hail stones were found in protected places the second day after the storm. Estimated damage, $200,000.

Average accumulated departures for July, 1918.

Districts.	Temperature			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	° F.	° F.	° F.	Ins.	Ins.	Ins.	0-10.		P. ct.	
New England	68.3	−0.5	− 9.3	2.70	−0.90	− 4.50	5.3	+0.2	83	+ 3
Middle Atlantic	72.6	−2.0	− 3.4	3.03	−1.30	− 2.20	5.1	+0.2	71	− 2
South Atlantic	75.7	−2.3	+ 2.7	4.85	−1.20	− 9.00	6.3	+1.5	75	− 4
Florida Peninsula	81.9	−0.4	+ 3.6	3.54	−2.90	−10.20	5.1	+0.1	74	− 4
East Gulf	79.0	−1.3	+ 6.0	3.09	−2.20	− 6.10	5.2	−0.2	71	− 7
West Gulf	83.0	+1.1	+ 5.0	0.90	−2.30	− 6.90	3.5	−0.8	64	− 9
Ohio Valley and Tennessee	73.6	−2.9	− 4.3	2.53	−1.50	− 4.10	5.2	+0.4	68	− 3
Lower Lakes	70.0	−1.7	− 6.5	2.07	−1.30	− 2.40	4.8	+0.2	68	− 2
Upper Lakes	66.3	−1.7	− 8.0	1.54	−1.60	− 1.80	4.4	−0.3	70	− 3
North Dakota	66.3	−2.8	+11.5	2.48	−0.50	− 3.20	4.5	+0.3	67	+ 1
Upper Mississippi Valley	73.9	−1.5	− 0.8	3.14	−0.60	− 2.50	4.6	+0.2	66	− 3
Missouri Valley	75.7	−0.1	+ 9.9	2.35	−1.40	− 4.40	4.6	+0.4	64	− 1
Northern slope	67.5	−0.6	+ 6.8	2.25	+0.60	+ 0.90	4.8	+1.1	59	+ 3
Middle slope	77.2	+0.4	+ 7.3	1.09	−1.30	− 1.30	4.4	+0.3	58	− 3
Southern slope	82.6	+2.2	+11.3	1.09	−1.70	− 4.40	3.2	−1.0	49	−11
Southern Plateau	77.9	−1.1	+ 1.4	1.00	−0.20	− 0.30	3.2	−0.2	43	+ 3
Middle Plateau	72.0	−0.8	+ 3.7	0.58	+0.10	− 1.10	3.5	+0.5	38	+ 2
Northern Plateau	72.5	+1.6	+13.8	0.77	+0.30	− 1.60	4.4	+1.6	42	− 1
North Pacific	62.0	0.0	+ 6.6	0.98	+0.30	− 3.30	5.6	+1.0	74	− 1
Middle Pacific	64.4	−1.1	+ 3.3	0.04	0.00	− 6.50	3.3	+0.4	59	− 2
South Pacific	70.6	+0.7	+12.3	0.02	0.00	+ 2.50	2.7	0.0	66	+ 2

WEATHER CONDITIONS OVER THE NORTH ATLANTIC DURING JULY, 1917.

The data presented are for July, 1917, and comparison and study of the same should be in connection with those appearing in the REVIEW for that month.

Chart IX (XLVI–63) shows for July, 1917, the averages of pressure, air temperature, water surface temperature, and prevailing direction of the wind at 7 a. m. 75th Meridian Time (Greenwich mean noon).

PRESSURE.

The distribution of the average pressure for the month, as shown on Chart IX, presented no unusual features, as

the North Atlantic, or Azores HIGH, was nearly normal in all respects, and the isobar of 29.85 inches, that marks the southern limit of the Icelandic LOW, was near its usual position.

The pressure changes from day to day were comparatively small over the greater part of the ocean, and the means of the three decades of the month differed but little in southern waters, while north of the 40th parallel the mean for the first decade was somewhat larger than the average of the last 21 days, as shown in the following table, which gives for a number of 5-degree squares the average pressure for each of the three decades of the month, as well as the highest and lowest individual readings reported within the respective squares.

Pressure over the North Atlantic Ocean during July, 1917, by 5-degree squares.

Position of 5-degree square.		Decade means.			Extremes.			
					Highest.		Lowest.	
Latitude.	Longitude.	I.	II.	III.*	Pressure.	Date.	Pressure.	Date.
°	°	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*July.*	*Inches.*	*July.*
60–65 N	20–25 W	30.08	29.82	29.80	30.42	3	29.58	15
60–65 N	0– 5 E	30.23	29.92	29.97	30.43	4	29.60	16
55–60 N	35–40 W	29.89	29.84	29.73	30.11	10	29.60	15, 28
55–60 N	10–15 W	30.14	29.84	29.97	30.32	4	29.56	26
50–55 N	55–60 W	29.99	29.89	29.79	30.20	8	29.48	29
50–55 N	25–30 W	29.97	29.82	29.87	30.19	10	29.67	17
50–55 N	0– 5 E	30.09	30.02	30.06	30.30	12	29.80	8, 19
45–50 N	65–70 W	30.00	29.89	29.90	30.20	7, 25	29.67	12
45–50 N	40–45 W	30.01	30.01	29.90	30.20	5	29.76	3
45–50 N	10–15 W	30.11	30.04	30.11	30.32	1	29.86	7
40–45 N	50–55 W	30.11	30.13	30.06	30.31	20	29.83	31
40–45 N	25–30 W	30.19	30.10	30.16	30.32	30	30.00	11, 16, 21
35–40 N	75–80 W	30.01	30.02	30.04	30.24	20	29.68	11
35–40 N	35–40 W	30.29	30.23	30.23	30.40	5, 25	30.02	27
35–40 N	10–15 W	30.13	30.17	30.14	30.30	10	29.99	6
30–35 N	50–55 W	30.28	30.25	30.20	30.42	3	30.00	10
30–35 N	25–30 W	30.29	30.23	30.25	30.40	9	30.10	20
25–30 N	90–95 W	29.99	29.99	30.04	30.12	30	29.90	11
25–30 N	60–65 W	30.17	30.22	30.18	30.31	1, 14	30.00	8
25–30 N	15–20 W	30.13	30.15	30.14	30.30	26	30.00	1
15–20 N	35–40 W	30.03	30.04	30.03	30.19	6	29.98	19, 24
10–15 N	80–85 W	29.90	29.88	29.92	29.98	26	29.82	20

* Mean of last 11 days of the month.

The mean and extreme values presented in the above table are based on the pressure for each square on the M. S. daily synoptic charts of the North Atlantic compiled by the marine section of the Weather Bureau.

GALES.

The most remarkable feature of the month was the absence of winds with gale force. On only one day was a fresh gale reported; it occurred on the 12th when a vessel near latitude 32° 30′, longitude 71° 30′ encountered a southwesterly gale of 48 miles an hour. The northern steamer lanes were remarkably free from heavy weather, as north of the 40th parallel winds with a velocity as high as 40 miles an hour were recorded on only three days. In southern waters high winds were somewhat more frequent, although velocities of over 35 miles an hour were observed at only widely scattered points, and there were no signs of tropical hurricanes.

On July 1 and 2 a LOW of slight intensity covered a large portion of eastern Canada and the Gulf of St. Lawrence, moderate winds and fog prevailing along the coast between St. Johns, N. F., and Boston. From the 3d to the 6th this LOW covered a large territory between the 25th meridian and the American coast north of the 50th parallel. The conditions remained about the same as on the 2d, with light to moderate winds and a few scattered reports of fog. On the 8th a moderate LOW surrounded the greater part of the British Isles, extending into the English Channel. Drifting slowly eastward, the center of the LOW was near Yarmouth, England, on the 9th, with light to moderate winds prevailing on both dates.

On the 8th two vessels between the Island of Haiti and the Barbados, encountered westerly winds of 40 miles an hour, although there was no well-developed depression in that region and vessels near by reported only moderate velocities.

On the 11th there was a slight disturbance central near Norfolk, Va.; it drifted slowly along the coast in a northeasterly direction, accompanied by light to moderate winds and fog, and on the 15th was off the coast of Labrador. On the 16th and 17th a large but shallow depression extended over the greater part of the eastern division of the steamer lanes; it increased somewhat in intensity, and on the 18th the center was near the north coast of Ireland, where the barometer reading was 29.59 in. This LOW continued in its slow easterly movement, and on the 19th covered the North Sea, extending into the Scandinavian Peninsula on the north. The usual moderate weather probably prevailed, although it was impossible to determine the conditions accurately on account of lack of observations.

From the 22d to the 24th the northern division of the ocean was occupied by a large, poorly defined LOW of slight intensity. By the 25th it had assumed more definite proportions, the center being near latitude 58°, longitude 31°, where the barometer reading was 29.68 inches. Like the other depressions of the month it was of slight intensity.

From the 27th to the 29th there was a LOW over the territory between St. Johns, N. F., and the south coast of Greenland. On the latter date vessels in the eastern and southern quadrants encountered winds of 40 miles an hour, and fog prevailed off the banks of Newfoundland. This disturbance drifted slowly southward, and on the 31st extended to the 40th parallel, the force of the wind having lessened somewhat since the 29th.

AIR TEMPERATURE.

The average monthly temperature of the air over the ocean, as compared with the normal, varied considerably in different localities. Over the greater part of the northern steamer lanes, and in the northeast trade wind region, the temperatures were above the normal, the departures ranging from 1° to 5°. In the region between the 30th and 45th parallels and the 40th meridian and the American coast, as well as in the Caribbean Sea and the Gulf of Mexico, it was somewhat colder than usual, negative departures of from 1° to 4° prevailing.

As usual in July, the daily fluctuations in temperature were not large. In the 5° square that includes St. Johns, N. F., where the greatest variations occurred, the temperature ranged from 49° on the 2d to 60° on the 19th.

The following table gives the temperature departures for the month at a number of Canadian and United States Weather Bureau stations on the Atlantic and Gul coasts.

	°F.		°F.
St. Johns, N. F.	−0.1	Norfolk, Va.	−1.2
Chatham, N. B.	+1.0	Hatteras, N. C.	−0.2
Halifax, N. S.	+1.5	Charleston, S. C.	−0.5
Eastport, Me.	−1.4	Key West, Fla.	−0.3
Portland, Me.	+0.8	Tampa, Fla.	+1.9
Boston, Mass.	+2.0	Mobile, Ala.	+0.9
Nantucket, Mass.	0.0	New Orleans, La.	+1.3
Block Island, R. I.	+0.3	Galveston, Tex.	+0.3
New York, N. Y.	+0.6	Corpus Christi, Tex.	−0.5

WATER SURFACE TEMPERATURE.

The average monthly temperature of the surface water, when compared with the normal, did not show departures

varying materially from those of the air over the greater part of the ocean. In the northeast trade wind region and Gulf of Mexico the departures were rather irregular, ranging from −1° to +4°; south of the 25th parallel and between the 40th and 80th meridians the water temperatures were practically normal.

The greatest daily fluctuations occurred in the square between latitude 40°–45°, longitude 55°–60°, where the water thermometer readings ranged from 50° on the 1st to 70° on the 23d and on the last three days of the month.

FOG.

Off the banks of Newfoundland the normal percentage of days on which fog is observed during July ranges from 50 to 55. For the month under discussion it prevailed in that region on 12 days, a percentage of 39, while the maximum amount occurred in the square between latitude 40°–45°, longitude 60°–65°, where it was reported on 22 days, a percentage of 71.

Over the steamer lanes fog was somewhat below the normal; while at the Azores, where it seldom occurs, it was observed on two days.

Winds of 50 mis./hr. (22.4 m./sec.) or over, during July, 1918.

Station.	Date.	Velocity.	Direction.	Station.	Date.	Velocity.	Direction.
Buffalo, N. Y.	1	60	sw.	Pocatello, Idaho	8	50	s.
Ellendale, N. Dak.	20	52	sw.	Point Reyes Light, Cal.	9	58	nw.
Do.	21	53	n.	Do.	12	54	nw.
El Paso, Tex.	19	50	ne.	Do.	21	61	nw.
Hatteras, N. C.	12	50	nw.	Do.	23	53	nw.
Mount Tamalpais, Cal.	21	54	nw.	Do.	25	50	nw.
Do.	22	52	nw.				
Do.	23	55	nw.				

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by section, July, 1918.

Section.	Temperature.							Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.					Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest. Date.			Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.	In.	In.		In.		In.
Alabama	78.1	−1.9	Thomasville	104	7	St. Bernard	48 13	3.87	−1.28	Robertsdale	7.42	Cochrane	1.32
Arizona	78.0	0.0	Aztec	120	28†	Fort Valley	34 13	2.12	−0.29	Fort Valley	7.85	Mohawk	0.00
Arkansas	79.6	−0.1	Bee Branch	111	25	Eureka Springs	49 1	1.53	−2.53	Mountain Home	5.08	Conway	0.06
California	71.5	−2.5	Greenland Ranch	120	4†	2 stations	20 13†	0.07	+0.03	Tamarack	1.58	118 stations	0.00
Colorado	65.6	−0.3	Sedgwick	110	3	Fraser	26 1	2.66	+0.52	Willard	7.06	Leadville	0.28
Florida	80.2	−1.2	Wausau	101	6	Hilliard	57 10	5.50	−1.71	Orlando	12.30	Sand Key	1.20
Georgia	78.1	−1.7	3 stations	103	6†	2 stations	48 13	4.78	−0.92	Savannah	8.94	Lumber City	2.10
Hawaii (June)	73.0	0.0	2 stations	94	10†	2 stations	51 3†	4.92	+0.22	Eke, Maui	30.50	5 stations	0.00
Idaho	67.6	+1.2	2 stations	111	18	Stanley	15 1	0.96	+0.10	Spencer	5.04	Sunnyside	0.09
Illinois	73.8	−2.1	2 stations	105	26†	Mt. Carroll	42 31	2.38	−1.23	Galva	5.35	Sparta	0.11
Indiana	72.3	−3.0	Bedford	102	4†	Valparaiso	40 31	3.14	−0.40	Butlerville	7.96	South Bend	0.72
Iowa	73.1	−1.0	Clarinda	105	28	Audubon	40 1	3.17	−0.79	Postville	8.05	Albia	0.26
Kansas	78.3	+0.6	Abilene	110	25	Dresden	45 1	2.53	−1.13	Norton	7.67	Clyde	0.28
Kentucky	73.8	−2.9	Paducah	103	26	Eubank	46 9	3.28	−1.02	Cloverport	8.25	Mayfield	0.43
Louisiana	82.4	+0.7	Monroe	109	25	Kelly	51 3	3.16	−3.26	Schriever	9.30	Shreveport	T.
Maryland-Delaware	72.6	−2.7	2 stations	99	21†	Oakland, Md.	38 3	3.05	−1.17	Sudlersville, Md.	5.14	Public Landing, Md	0.60
Michigan	66.9	−2.0	2 stations	100	22†	Roscommon	26 1	1.73	−1.11	Grand Marais	5.24	Adrian	0.24
Minnesota	68.0	−0.7	New London	103	19	Duluth	32 8	3.35	−0.20	New Richland	7.02	Duluth	1.23
Mississippi	79.7	−1.2	Cleveland	106	26	2 stations	52 2†	2.73	−2.58	Leaksville	6.96	Austin	0.51
Missouri	77.1	+0.2	Harrisonville	110	27	Cassville	41 1	1.76	−2.49	Grant City	4.94	Jackson	0.21
Montana	65.8	+0.4	Crow Agency	104	3	Bowen	18 4	1.99	+0.49	Pinegrove	7.79	Valentine	0.23
Nebraska	74.3	−0.2	Holdrege	110	8	Gordon	36 1	3.17	−0.26	Hershey	7.70	Hastings	1.10
Nevada	72.9	−0.5	Logandale	112	29	Tecoma	21 5	0.33	−0.10	Smith	2.50	12 stations	0.00
New England	68.8	−0.3	Amherst, Mass.	100	22	Somerset, Vt.	35 2	3.46	−0.13	Patten, Me.	9.60	Vernon, Vt.	0.90
New Jersey	72.2	−1.4	Elizabeth	101	22	Layton	39 3	3.93	−0.90	Long Branch	13.60	Cape May	1.20
New Mexico	72.5	+0.2	Artesia	107	11	Elizabethtown	31 28	2.43	−0.28	Nogal	7.28	Glorieta Ranch	0.27
New York	68.9	−0.8	Troy	103	23	Indian Lake	34 3	3.33	−0.37	Gloversville	6.88	Elmira	0.66
North Carolina	73.0	−3.5	Lincolnton	103	5	Highlands	39 13	5.52	−0.37	Newbern	12.11	Brevard	1.42
North Dakota	65.5	−2.0	Grand Rapids	102	20	2 stations	34 5†	2.71	+0.10	Energy	6.08	Westhope	0.53
Ohio	71.3	−2.3	Paulding	101	21	3 stations	38 2†	2.61	−1.56	New Carlisle	6.21	Vickery	0.36
Oklahoma	82.1	+1.3	Mutual	111	15	Jefferson	50 1	1.38	−1.74	Hurley	5.56	2 stations	T.
Oregon	67.0	+1.1	Echo	111	17	Lapine	20 3†	0.66	+0.11	Hilgard	2.82	4 stations	0.00
Pennsylvania	70.1	−1.6	4 stations	99	21†	Mt. Pocono	35 3	3.05	−1.09	Mt. Pocono	9.96	Shawmont	0.77
Porto Rico	78.7	−0.1	Isabela	96	28	Rio Piedras	58 29	5.40	−1.14	Maricas	14.75	Ponce	0.48
South Carolina	77.5	−2.3	Little Mountain	103	6	Santuck	50 8	5.02	−0.80	Bowman	9.70	Columbia	1.15
South Dakota	70.1	−0.8	Bellefourche	105	31	McIntosh	33 26	3.20	+0.59	Mitchell	6.69	McIntosh	0.43
Tennessee	74.7	−2.4	Clarksville	102	4†	2 stations	42 3†	3.57	−1.07	Copperhill	8.77	Union City	0.68
Texas	84.8	+2.3	3 stations	111	9†	Brownfield	52 1	1.05	−1.78	Port Arthur	6.48	9 stations	0.00
Utah	69.7	−0.4	St. George	108	29†	Black's Fork	28 25	1.61	+0.56	Trout Creek R. S.	5.01	Lemay	0.17
Virginia	71.7	−3.7	3 stations	98	22†	Burkes Garden	39 3	3.50	−0.81	Blacksburg	8.26	Richmond	1.05
Washington	66.8	+0.6	Wahiuke	115	16	Paradise Inn	30 3	1.12	+0.31	Wallace	3.38	Mary Hill	0.00
West Virginia	70.3	−3.1	Wheeling	101	28	Bluefield	38 3	3.18	−1.19	Grafton	6.90	Breading	1.04
Wisconsin	67.8	−1.4	2 stations	100	12†	Big St. Germain Dam	29 31	2.71	−1.28	Prairie du Chien	7.32	Plum Island	0.49
Wyoming	64.1	−0.3	2 stations	102	31	Foxpark	18 1	2.13	+0.92	Burns	5.74	Hyattville	0.40

† Other dates also.

DESCRIPTION OF TABLES AND CHARTS.

(*See* this REVIEW, January, 1918, p. 48.)

TABLE I.—*Climatological data for Weather Bureau Stations, July, 1918.*

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.										Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Precipitation.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.					
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F*		°*F*	°*F.*		°*F*	°*F.*	°*F.*	°*F.*	°*F.*	%	*In.*	*In.*		*Miles.*					*0–10*	*In.*	*In.*
New England.							**68.3**	**−0.4**											**83**	**2.70**	**−0.9**								**5.3**		
East port	76	67	85	29.89	29.98	+ .05	57.6	−2.2	82	28	65	46	10	50	26	55	54	92	2.98	−0.4	13	6,076	s.	33	ne.	23	3	10	18	7.4		
Greenville	1,070	6	....	28.82	29.97	.....	66.0	.....	90	23	75	49	10	57	29	...	...	...	8.25	.....	22	.....	.....	...	.....	...	...	...	...	.....	.....	.....
Portland, Me.	103	82	117	29.86	29.98	+ .03	66.7	−1.3	94	23	74	52	9	59	26	62	60	82	2.94	−0.3	16	5,025	s.	24	s.	16	9	9	13	6.0	.....	.....
Concord	288	70	79	29.67	29.97	+ .01	69.6	+0.5	95	22	81	48	3	58	36	...	...	...	1.74	−2.0	12	2,190	s.	9	sw.	30	15	11	5	4.1	.....	.....
Burlington	404	11	48	29.54	29.96	+ .02	69.0	+0.8	90	22	78	47	3	60	31	...	...	...	2.95	−0.8	13	5,820	s.	33	sw.	29	11	10	10	5.5	.....	.....
Northfield	876	12	60	29.06	29.98	+ .04	66.0	−0.6	93	22	78	38	3	54	38	62	60	82	1.77	−1.9	10	4,179	s.	24	se.	1	3	15	13	6.8	.....	.....
Boston	125	115	188	29.84	29.97	+ .01	71.0	−0.3	98	23	79	54	9	63	24	65	63	80	2.64	−0.7	13	5,876	sw.	32	w.	17	9	11	11	5.5	.....	.....
Nantucket	12	14	90	29.96	29.98	.00	67.0	−0.5	88	21	74	51	6	60	22	64	63	94	1.47	−1.2	11	9,854	sw.	43	ne.	31	11	9	8	5.2	.....	.....
Block Island	26	11	46	29.95	29.98	+ .01	68.6	+0.5	89	22	75	55	9	62	20	65	63	89	1.75	−1.6	7	9,443	sw.	42	nw.	4	13	9	9	4.6	.....	.....
Narragansett Pier	....	9	....	.....	.....	.....	68.8	−1.1	88	30	76	50	9	61	24	...	...	...	2.57	.....	9	.....	sw.	...	.....	...	12	11	8	.....	.....	.....
Providence	160	215	251	29.81	29.98	+ .01	71.4	−2.0	97	23	80	54	9	62	26	64	61	75	4.44	+0.9	8	7,052	sw.	48	nw.	17	8	16	7	5.2	.....	.....
Hartford	159	122	140	29.81	29.98	+ .01	72.0	+0.4	97	22	82	51	3	62	29	65	63	79	2.76	−1.4	9	4,842	s.	31	nw.	17	11	14	6	4.2	.....	.....
New Haven	106	117	155	29.88	29.99	+ .02	72.2	+0.3	95	23	81	52	3	63	28	65	61	72	4.31	−0.5	9	5,774	s.	34	sw.	17	13	11	7	4.3	.....	.....
Middle Atlantic States.							**72.6**	**−2.0**											**71**	**3.03**	**−1.3**								**5.1**		
Albany	97	102	115	29.86	29.96	.00	71.9	+0.1	99	22	81	48	3	63	31	64	61	72	1.59	−2.3	9	4,706	s.	28	s.	29	10	12	9	5.2	.....	.....
Binghamton	871	10	69	29.08	30.00	+ .03	69.2	−0.7	92	21	80	44	3	59	34	...	...	...	5.63	+2.1	11	2,861	sw.	19	n.	6	8	12	11	5.2	.....	.....
New York	314	414	454	29.06	29.98	.00	72.7	−0.8	94	22	80	56	3	65	25	64	59	67	3.61	−0.9	8	9,740	sw.	48	nw.	14	7	15	9	5.7	.....	.....
Harrisburg	374	94	104	29.62	30.01	+ .03	73.2	−1.3	95	21	83	53	3	64	33	64	58	62	3.34	−0.5	10	4,148	nw.	24	s.	29	7	16	8	5.5	.....	.....
Philadelphia	117	123	190	29.86	29.98	.00	75.4	−0.4	95	22	84	60	3	67	27	66	62	65	2.46	−1.9	9	6,400	nw.	27	nw.	2	9	15	7	5.2	.....	.....
Reading	325	81	98	29.66	30.00	.....	73.6	.....	95	21	84	51	3	63	31	64	59	64	2.43	−1.8	11	4,054	n.	36	nw.	19	10	13	8	4.9	.....	.....
Scranton	805	111	119	29.16	30.01	+ .03	70.4	−1.4	95	21	81	46	3	60	34	63	60	74	2.59	−1.2	12	4,062	sw.	27	sw.	10	8	11	12	5.8	.....	.....
Atlantic City	52	37	48	29.94	29.99	+ .01	72.0	−0.5	85	23	78	55	3	66	23	67	64	78	1.84	−1.9	6	4,693	s.	23	ne.	31	14	13	4	3.8	.....	.....
Cape May	18	13	49	30.02	30.03	+ .05	72.0	−1.4	...	...	...	...	...	...	...	...	...	...	1.20	−2.6	...	...	...	...	...	...	...	...	...	3.6	.....	.....
Sandy Hook	22	10	57	29.97	29.99	.....	72.8	.....	96	22	80	59	3	66	25	66	63	77	4.93	.....	10	8,671	nw.	47	nw.	14	12	12	7	5.2	.....	.....
Trenton	130	153	183	29.78	29.98	.....	73.2	.....	98	22	83	54	3	64	29	65	60	69	4.97	+0.2	9	6,684	s.	39	n.	19	10	14	7	5.2	.....	.....
Baltimore	123	100	113	29.88	30.00	+ .02	75.4	−1.9	94	22	84	58	9	67	25	66	60	63	2.28	−2.5	8	4,435	s.	33	s.	29	8	13	10	5.1	.....	.....
Washington	112	62	85	29.88	30.00	.00	74.4	−2.4	96	21	85	53	3	64	31	65	61	68	3.79	−0.9	14	3,837	nw.	26	s.	29	12	9	10	4.7	.....	.....
Lynchburg	681	153	188	29.29	30.02	+ .01	72.8	−4.5	92	4	83	52	3	62	34	66	63	75	3.75	−0.3	13	3,621	n.	39	sw.	12	9	12	10	5.3	.....	.....
Norfolk	91	170	205	29.92	30.02	+ .02	75.0	−3.4	91	21	83	60	3	67	25	68	64	75	3.06	−2.7	11	6,931	se.	46	w.	10	13	10	8	4.8	.....	.....
Richmond	144	11	52	29.87	30.02	+ .01	73.8	−5.4	92	25	84	54	3	64	29	66	63	72	1.05	−3.4	14	4,218	se.	27	se.	29	7	10	14	6.2	.....	.....
Wytheville	2,293	49	55	27.72	30.03	+ .02	67.8	−4.8	87	5	78	47	3	58	34	61	58	78	4.93	+0.5	16	3,037	nw.	23	w.	5	8	13	10	5.3	.....	.....
South Atlantic States.							**76.7**	**−2.3**											**75**	**4.85**	**−1.2**								**6.3**		
Asheville	2,255	70	84	27.76	30.05	+ .03	68.9	−2.8	87	7	79	51	9	58	30	62	59	78	2.74	−2.1	14	3,942	nw.	26	nw.	1	6	17	8	5.6	.....	.....
Charlotte	773	153	161	29.20	30.02	.00	76.0	−2.7	96	5	86	56	13	66	29	67	63	72	1.90	−3.6	14	2,975	n.	19	nw.	23	7	11	13	6.2	.....	.....
Hatteras	11	12	50	29.99	30.00	− .01	75.0	−3.6	90	7	82	60	4	68	20	70	68	80	7.10	+1.0	13	8,135	n.	50	nw.	12	8	16	7	5.4	.....	.....
Manteo	12	4	46	.....	.....	.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	.....	.....
Raleigh	376	103	110	29.62	30.01	− .01	75.0	−3.5	94	6	84	57	9	65	23	67	63	73	5.37	−0.7	13	4,290	n.	33	se.	26	6	9	16	6.5	.....	.....
Wilmington	78	81	91	.....	30.01	.00	76.6	−2.1	96	6	85	58	13	68	24	...	...	...	6.41	−0.6	12	4,477	sw.	29	n.	12	12	12	7	.....	.....	.....
Charleston	48	11	92	29.97	30.02	− .01	79.4	−1.9	100	7	87	64	13	72	25	71	69	74	7.69	+0.4	13	6,443	s.	32	nw.	8	11	9	11	5.0	.....	.....
Columbia, S. C.	351	41	57	29.65	30.02	.00	78.9	−1.6	98	6	89	60	13	69	30	68	64	68	1.15	−4.9	10	4,116	ne.	27	w.	18	9	10	12	5.8	.....	.....
Greenville, S. C.	1,013	113	122	28.94	30.01	.....	75.2	.....	92	6	84	60	13	69	32	68	64	68	2.14	.....	15	4,781	ne.	31	nw.	7	12	11	8	5.1	.....	.....
Augusta	180	62	77	29.82	30.01	− .01	79.3	−1.2	99	6	89	61	13	69	32	71	69	76	3.84	−1.4	9	3,410	nw.	37	nw.	8	7	8	16	6.4	.....	.....
Savannah	65	150	194	29.95	30.02	− .01	79.0	−1.5	98	7	88	63	13	70	27	71	68	75	8.94	+2.8	12	6,587	sw.	34	nw.	20	10	8	13	5.8	.....	.....
Jacksonville	43	200	245	29.98	30.03	.00	79.0	−1.9	93	7	86	69	21	72	22	72	70	77	3.35	−2.8	12	8,413	sw.	48	sw.	20	14	10	7	4.8	.....	.....
Florida Peninsula.							**81.9**	**−0.4**											**74**	**3.54**	**−2.9**								**5.1**		
Key West	22	10	64	29.99	30.01	−.02	83.5	−0.2	91	30	89	71	6	78	14	76	72	70	1.72	−1.9	11	5,566	e.	27	sw.	20	17	12	2	3.8	.....	.....
Miami	25	71	79	30.00	30.03	.....	80.4	−1.5	90	1	87	69	14	74	19	75	73	79	4.01	−3.2	17	4,913	e.	22	nw.	9	5	17	9	6.0	.....	.....
Sand Key	23	39	72	29.97	30.00	−.03	82.4	.....	89	19	85	73	3	79	12	76	73	73	1.20	.....	10	7,237	e.	34	ne.	3	14	15	2	4.1	.....	.....
Tampa	35	79	92	29.99	30.02	−.02	81.5	+0.3	95	21	89	70	16	74	22	73	71	74	4.88	−3.6	14	4,832	ne.	30	sw.	30	3	15	13	6.6	.....	.....
East Gulf States.							**79.0**	**−1.3**											**71**	**3.09**	**−2.2**								**5.2**		
Atlanta	1,174	190	216	28.83	30.04	+.02	76.6	−1.0	94	7	85	59	2	68	23	67	62	66	2.47	−2.3	14	5,745	w.	36	w.	8	10	3	18	6.1	.....	.....
Macon	370	78	87	29.64	30.03	+.01	77.9	−1.8	96	7	88	61	14	68	31	69	65	69	3.57	−1.1	12	3,382	s.	28	w.	17	5	15	11	6.2	.....	.....
Thomasville	273	49	58	29.73	30.02	−.01	79.2	−2.6	95	6	89	62	5	69	29	70	67	72	2.46	−2.9	9	2,951	ne.	20	sw.	21	10	10	11	5.4	.....	.....
Pensacola	56	149	185	29.96	30.02	+.01	79.4	−2.0	92	23	85	68	1	74	21	73	71	77	6.02	−1.2	11	7,772	s.	46	s.	1	12	13	6	4.5	.....	.....
Anniston	741	9	57	29.27	30.05	+.03	75.8	−2.1	95	7	87	53	13	64	34	...	...	...	6.69	+2.0	12	3,016	se.	25	w.	16	12	11	8	4.5	.....	.....
Birmingham	700	11	48	29.24	30.04	+.03	77.6	−3.9	95	7	88	58	2	68	27	68	64	72	3.34	−1.4	11	3,414	n.	22	nw.	18	14	12	5	4.4	.....	.....
Mobile	57	125	161	29.96	30.02	+.01	81.0	+0.5	97	24	90	66	2	72	25	73	70	77	2.85	−4.2	12	5,661	sw.	37	se.	24	10	12	9	5.3	.....	.....
Montgomery	223	100	112	29.78	30.02	.00	79.5	−1.5	97	6	89	62	2	70	25	69	65	67	2.08	−2.6	11	3,828	e.	25	sw.	25	8	11	12	5.7	.....	.....
Corinth	469	6	....	.....	.....	.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	.....	.....
Jackson	304	5	....	.....	.....	.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	.....	.....
Meridian	375	85	93	29.63	30.01	−.01	78.4	−1.6	96	6	89	59	14	68	32	69	64	66	0.56	−3.9	6	3,258	ne.	27	n.	27	11	14	6	4.5	.....	.....
Vicksburg	247	65	74	29.76	30.03	+.01	80.8	+0.4	98	8	91	65	2	71	25	70	65	66	1.98	−2.4	7	4,008	se.	33	ne.	30	7	18	6	5.3	.....	.....
New Orleans	51	76	84	29.96	30.01	+.01	83.1	+1.8	97	24	91	72	20	76	20	74	72	75	2.03	−4.4	13	4,026	sw.	25	n.	1	9	14	8	5.3	.....	.....
West Gulf States.							**83.0**	**+1.1**											**64**	**0.90**	**−2.3**								**3.5**		
Shreveport	249	77	93	29.74	30.00	+.02	84.2	+2.1	102	28	96	66	3	72	30	70	62	54	T.	−3.7	0	4,639	ne.	30	se.	21	26	3	2	2.1	.....	.....
Bentonville	1,303	11	44	28.68	30.02	+.05	76.3	−2.2	100	28	88	53	1	64	33	...	...	...	1.18	−3.1	6	3,153	s.	15	s.	25	20	3	8	3.7	.....	.....
Fort Smith	457	79	94	29.51	29.98	+.01	82.2	+1.2	104	28	94	62	1	70	33	69	62	56	0.50	−3.3	3	4,596	e.	30	n.	27	16	9	6	4.2	.....	.....
Little Rock	357	139	147	29.64	30.00	+.01	80.4	+0.2	101	25	90	64	13	71	25	68	62	59	0.94	−3.0	5	4,677	e.	33	n.	29	13	10	8	4.6	.....	.....
Brownsville	57	4	26	.....	.....	.....	85.6	.....	102	30	96	70	2	75	30	...	...	...	1.34	.....	6	.....	s.	...	.....	...	...	...	...	.....	.....	.....
Corpus Christi	20	69	77	29.97	29.99	+.03	82.2	−0.5	94	31	88	73	2	77	19	76	75	82	0.30	−1.4	5	9,322	se.	35	se.	21	18	10	3	3.2	.....	.....
Dallas	512	109	117	29.46	30.00	.....	85.2	.....	102	29	95	66	2	75	28	...	...	...	0.84	.....	3	6,200	s.	34	nw.	11	20	9	2	3.1	.....	.....
Fort Worth	670	106	114	29.26	29.95	−.01	85.1	+1.4	101	8	86	67	2	74	28	71	65	57	1.10	−1.9	4	7,313	se.	30	se.	22	16	12	3	4.1	.....	.....
Galveston	54	106	114	29.95	30.01	+.03	83.6	+0.6	92	19	88	70	2	79	18	76	73	76	2.24	−1.7	5	7,258	s.	36	s.	2	8	20	3	4.7	.....	.....
Houston	138	111	121	29.86	30.00	.....	84.2	+1.2	98	18	94	69	2	75	25	...	...	...	6.11	.....	6	5,018	se.	36	e.	2	16	13	2	3.5	.....	.....
Palestine	510	64	72	29.47	29.98	+.01	84.2	+2.7	102	29	96	66	3	73	29	72	67	65	0.95	−2.8	2	4,835	ne.	30	n.	12	24	5	2	3.1	.....	.....
Port Arthur	34	58	66	29.96	30.00	.....	82.2	.....	94	18	90	65	21	74	25	75	73	79	6.48	.....	8	5,611	sw.	37	sw.	21	14	14	3	3.7	.....	.....
San Antonio	701	119	132	29.25	29.95	.00	85.2	+2.8	104	18	97	68	6	74	31	72	66	62	1.68	−0.5	3	5,726	s.	30	se.	9	20	9	2	2.5	.....	.....
Taylor	582	55	63	29.40	30.01	+.05	85.5	+2.8	105	18	97	67	7	74	30	...	...	...	0.10	−2.5	2	6,064	se.	34	ne.	12	18	11	2	3.2	.....	.....

TABLE I.—*Climatological data for Weather Bureau Stations, July, 1918*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.												Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Precipitation.			Wind.						Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.						Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F*		°*F*	°*F.*		°*F*	°*F.*	°*F.*	°*F.*	°*F.*	%	*In.*	*In.*		*Miles*						*0-10*	*In.*	*In.*
Ohio Valley and Tennessee.							**73.6**	**−2.9**											**68**	**2.53**	**−1.5**										**5.2**		
Chattanooga	762	189	213	29.25	30.04	+.02	75.7	−2.1	94	6	85	58	3	66	29	66	62	68	4.47	+0.6	10	4,740	ne.	42	sw.	24	8	14	9	5.4	.....	.....
Knoxville	996	102	111	29.00	30.03	+.01	74.0	−2.2	92	5	84	55	13	64	29	66	62	73	1.85	−2.4	10	3,223	n.	21	n.	7	9	10	12	5.6	.....	.....
Memphis	399	76	97	29.63	30.05	+.05	79.0	−1.7	96	7	88	61	13	70	24	68	63	62	2.27	−1.2	6	4,563	n.	28	nw.	18	19	6	6	3.5	.....	.....
Nashville	546	168	191	29.48	30.05	+.04	76.2	−3.2	95	7	87	56	2	66	31	66	60	65	3.63	−0.7	9	5,004	ne.	37	n.	29	14	10	7	4.3	.....	.....
Lexington	989	193	230	29.00	30.05	+.04	72.6	−4.0	90	4	81	55	31	64	23	.....	.....	.....	2.01	−2.4	10	6,703	sw.	31	ne.	11	13	9	9	4.8	.....	.....
Louisville	525	219	255	29.48	30.06	+.06	75.0	−3.6	95	4	84	56	31	66	27	65	60	63	4.02	+0.3	7	5,909	n.	36	n.	11	12	13	6	4.5	.....	.....
Evansville	431	139	175	29.58	30.04	+.04	76.6	−2.7	96	23	86	56	31	67	26	67	62	64	1.45	−2.4	8	6,185	ne.	33	nw.	8	8	20	3	4.9	.....	.....
Indianapolis	822	194	230	29.17	30.04	+.05	73.0	−3.2	93	26	82	53	12	64	24	63	58	63	2.44	−1.7	8	6,927	ne.	37	n.	10	14	12	5	4.9	.....	.....
Terre Haute	575	96	129	29.42	30.02	.....	73.8	.....	95	23	84	53	31	64	28	66	63	72	2.84	.....	8	5,717	s.	45	e.	28	4	23	4	5.7	.....	.....
Cincinnati	628	11	51	29.37	30.04	+.04	72.4	−1.8	92	28	83	51	9	62	30	65	61	71	3.05	−0.5	11	3,871	s.	29	ne.	28	6	15	10	5.8	.....	.....
Columbus	824	173	222	29.18	30.04	+.04	72.3	−3.0	93	4	82	50	8	62	27	63	58	66	2.50	−1.2	10	6,726	nw.	49	nw.	11	6	13	12	6.1	.....	.....
Dayton	899	181	216	29.07	30.01	.....	72.1	−4.1	93	28	82	51	9	62	30	64	59	69	2.62	−0.7	8	5,736	ne.	39	ne.	28	5	18	8	6.0	.....	.....
Pittsburgh	842	353	410	29.14	30.03	+.03	72.0	−2.6	92	22	82	51	8	62	31	61	55	60	2.22	−2.2	6	6,843	nw.	39	nw.	29	8	8	15	6.1	.....	.....
Elkins	1,940	41	50	28.04	30.04	+.03	66.6	−3.9	87	21	78	41	9	56	35	60	58	81	1.68	−3.0	14	2,677	nw.	21	w.	1	5	14	12	6.5	.....	.....
Parkersburg	638	77	84	29.40	30.05	+.04	72.6	−3.0	94	5	84	48	9	61	33	65	61	70	1.28	−3.4	10	3,173	n.	30	nw.	25	15	10	6	4.8	.....	.....
Lower Lake Region.							**70.0**	**−1.7**														**2.07**	**− 1.3**									**4.8**		
Buffalo	767	247	280	29.18	30.00	+ .03	68.8	−1.4	90	24	76	50	2	62	21	61	57	70	1.37	− 2.0	8	9,633	sw.	60	sw.	1	12	7	11	5.1	.....	.....
Canton	448	10	61	29.48	29.95	.....	69.1	−1.4	93	22	79	48	31	59	30	.....	.....	.....	3.64	+ 0.4	11	5,904	sw.	42	sw.	1	19	8	4	3.5	.....	.....
Oswego	335	76	91	29.61	29.98	+ .02	67.0	−2.6	91	22	74	47	2	60	25	61	58	75	1.74	− 1.5	8	5,680	w.	28	sw.	1	14	8	9	4.5	.....	.....
Rochester	523	97	117	29.44	30.00	+ .03	70.2	−0.2	96	22	80	49	2	61	28	61	57	66	2.70	− 0.4	12	5,518	sw.	34	sw.	1	10	10	11	5.3	.....	.....
Syracuse	597	97	117	29.36	30.00	+ .03	69.4	−1.4	92	22	78	49	2	61	24	.....	.....	.....	2.22	− 1.5	11	6,573	s.	33	s.	1	10	15	6	5.2	.....	.....
Erie	714	130	166	29.54	30.01	+ .03	69.6	−2.2	90	26	77	52	2	62	26	63	58	69	4.96	+ 1.8	7	8,208	s.	42	w.	1	9	14	8	5.3	.....	.....
Cleveland	762	190	201	29.22	30.03	+ .04	70.3	−2.2	92	21	77	54	2	64	26	63	58	65	1.08	− 2.5	5	7,519	ne.	48	nw.	1	14	11	6	4.2	.....	.....
Sandusky	623	62	103	.....	.....	.....	71.3	−2.3	91	22	79	50	2	64	25	.....	.....	.....	1.32	− 2.5	5	6,933	ne.	46	nw.	29	5	19	7	5.6	.....	.....
Toledo	628	208	247	29.36	30.03	+ .04	71.6	−2.1	92	21	81	48	31	62	26	63	57	65	0.95	− 2.3	7	7,852	sw.	40	w.	1	11	16	4	4.3	.....	.....
Fort Wayne	856	113	124	29.14	30.00	.....	71.2	−2.3	93	26	82	50	31	60	27	62	57	65	1.37	.....	10	4,758	s.	36	s.	2	10	17	4	4.5	.....	.....
Detroit	730	218	245	29.26	30.04	+ .06	71.1	−0.9	94	21	81	48	31	61	28	62	58	68	0.74	− 2.7	6	6,749	sw.	36	nw.	1	9	18	4	4.9	.....	.....
Upper Lake Region.							**66.3**	**−1.7**											**70**	**1.54**	**− 1.6**										**4.4**		
Alpena	609	13	92	29.36	30.02	+ .05	64.6	+1.2	96	21	75	42	2	54	32	59	55	71	0.73	− 2.3	5	7,034	nw.	44	nw.	1	10	13	8	5.0	.....	.....
Escanaba	612	54	60	29.37	30.04	+ .06	65.8	−2.7	84	5	72	42	30	55	25	59	55	75	1.68	− 1.7	10	6,392	s.	30	nw.	1	18	8	5	3.6	.....	.....
Grand Haven	612	54	92	29.36	30.04	+ .05	67.0	−2.7	88	21	75	46	31	60	22	61	57	71	1.72	− 0.9	6	6,842	w.	29	n.	29	16	13	2	3.7	.....	.....
Grand Rapids	707	70	87	29.28	30.04	+ .05	71.6	−1.0	94	28	83	50	2	60	30	62	57	62	1.17	− 1.5	6	3,608	nw.	25	nw.	1	11	16	4	4.5	.....	.....
Houghton	684	62	90	29.29	30.01	+ .05	62.9	−2.4	91	21	73	44	8	53	30	.....	.....	.....	1.34	− 1.8	6	6,717	e.	45	w.	5	10	14	7	4.8	.....	.....
Lansing	878	11	62	29.10	30.02	.....	69.2	−1.9	94	26	82	42	31	56	34	62	58	70	1.96	− 1.3	6	2,971	sw.	17	nw.	1	6	14	11	5.8	.....	.....
Ludington	637	60	66	29.35	30.04	.....	63.7	.....	83	24	71	45	31	56	22	59	55	71	1.44	.....	8	5,958	s.	24	n.	29	15	14	2	3.7	.....	.....
Marquette	734	77	111	29.25	30.25	+ .09	62.9	−2.0	86	21	72	44	1	54	29	59	55	75	2.50	− 0.6	9	6,507	nw.	34	w.	5	11	13	7	4.9	.....	.....
Port Huron	638	70	120	29.33	30.02	+ .04	66.8	−2.2	93	21	76	43	2	57	33	61	57	72	0.50	− 2.2	6	6,559	ne.	40	w.	1	13	15	3	3.4	.....	.....
Saginaw	641	48	82	29.34	30.02	.....	69.4	.....	95	21	81	44	2	58	33	61	56	64	1.22	− 2.5	7	5,313	s.	40	nw.	1	13	14	4	4.2	.....	.....
Sault Sate Marie	614	11	61	29.32	30.01	+ .04	62.4	+0.5	91	21	73	38	2	52	35	58	54	76	2.03	− 0.7	6	5,908	w.	42	nw.	1	13	8	10	4.8	.....	.....
Chicago	824	140	310	29.17	30.05	+ .07	71.2	−1.2	93	21	78	53	1	65	22	63	59	67	2.66	− 1.0	12	6,856	ne.	28	nw.	28	16	10	5	4.3	.....	.....
Green Bay	617	109	144	29.37	30.02	+ .05	68.5	−1.0	94	22	78	49	8	59	28	61	57	69	1.52	− 2.0	7	5,595	s.	24	n.	29	10	12	9	5.6	.....	.....
Milwaukee	681	119	133	29.31	30.04	+ .07	68.3	−1.4	93	20	77	51	1	60	34	62	58	71	1.25	− 1.8	8	5,848	w.	35	sw.	4	17	7	7	4.1	.....	.....
Duluth	1,133	11	47	28.81	30.01	+ .06	63.3	−2.7	90	19	73	46	1	54	36	58	53	73	1.23	− 2.4	14	7,536	ne.	43	nw.	19	15	10	6	4.1	.....	.....
North Dakota.							**66.3**	**−2.8**											**67**	**2.48**	**− 0.5**										**4.5**		
Moorhead	940	8	57	29.02	30.02	+ .08	67.7	−1.0	99	20	80	46	1	55	37	61	58	72	2.68	− 1.1	8	5,368	se.	27	se.	27	22	5	4	2.7	.....	.....
Bismarck	1,674	8	57	28.27	30.03	+ .10	68.0	−2.2	97	31	82	44	29	54	41	58	52	62	2.02	0.0	7	6,763	e.	34	w.	4	14	11	6	4.5	.....	.....
Devils Lake	1,482	11	44	28.44	30.00	+ .07	63.2	−4.9	94	20	75	40	10	51	39	57	52	71	2.81	− 1.0	9	6,424	se.	35	nw.	3	11	10	10	5.5	.....	.....
Ellendale	1,457	10	56	28.47	30.01	.....	66.2	.....	97	19	79	42	10	53	43	60	56	74	2.64	.....	9	8,516	ne.	53	n.	21	5	18	8	5.5	.....	.....
Grand Forks	835	12	80	.....	.....	.....	64.8	.....	95	20	77	43	1	53	39	.....	.....	.....	4.04	.....	8	.....	se.	34	w.	4	19	6	6	.....	.....	.....
Williston	1,872	41	48	28.02	29.97	+ .05	66.2	−3.2	96	18	78	44	5	54	41	57	50	62	2.27	+ 0.2	9	6,450	se.	42	nw.	3	10	1	7	5.4	.....	.....
Upper Mississippi Valley.							**73.9**	**−1.5**											**66**	**3.14**	**− 0.6**										**4.6**		
Minneapolis	918	10	208	29.02	29.99	.....	70.6	.....	94	20	80	51	1	62	29	.....	.....	.....	5.07	+ 1.3	11	7,065	se.	38	nw.	19	9	10	12	5.9	.....	.....
St. Paul	837	201	216	29.11	30.01	+ .06	69.9	−2.2	91	20	79	50	1	61	27	.....	.....	.....	5.05	+ 1.6	12	7,465	se.	40	sw.	25	10	17	4	4.7	.....	.....
La Crosse	714	11	48	29.26	30.02	+ .06	70.2	−2.4	97	20	81	48	30	60	29	.....	.....	.....	4.80	+ 0.7	12	2,709	se.	23	nw.	22	12	8	11	5.3	.....	.....
Madison	974	70	78	29.02	30.04	+ .07	70.3	−2.1	92	21	80	51	30	61	27	62	57	66	2.33	− 1.7	12	4,893	s.	31	ne.	28	12	7	12	5.1	.....	.....
Wausau	1,247	4	.....	28.71	30.02	.....	65.6	.....	92	21	76	43	30	56	32	.....	.....	.....	3.90	.....	8	.....	se.	.....	.....	.....	16	5	10	4.5	.....	.....
Charles City	1,015	10	49	28.97	30.02	+ .06	71.1	−2.4	95	20	82	47	1	60	32	64	61	72	7.24	+ 3.7	10	3,621	se.	24	s.	3	13	12	6	4.8	.....	.....
Davenport	606	71	73	29.38	30.01	+ .06	74.1	−1.3	94	22	84	53	31	64	26	65	61	65	4.39	+ 0.8	9	4,455	e.	27	w.	6	15	10	6	4.3	.....	.....
Des Moines	861	84	97	29.11	30.00	+ .04	75.6	+0.1	98	27	87	53	1	65	32	65	60	63	1.18	− 2.7	7	4,721	n.	32	sw.	4	12	14	5	4.3	.....	.....
Dubuque	698	81	96	29.31	30.05	+ .08	72.3	−2.4	93	21	82	52	31	63	27	65	61	69	3.77	− 0.5	13	3,774	s.	25	nw.	3	15	7	9	4.6	.....	.....
Keokuk	614	64	78	29.37	30.04	+ .06	76.2	−0.8	97	20	86	55	1	66	28	66	61	63	1.08	− 3.0	8	4,498	s.	24	sw.	6	20	9	2	3.1	.....	.....
Cairo	356	87	93	29.63	30.00	.00	78.0	−0.6	95	24	87	60	9	69	27	68	63	65	0.74	− 2.7	5	4,604	s.	24	ne.	12	12	6	13	5.3	.....	.....
Peoria	609	11	45	29.38	30.05	+ .07	72.8	−2.6	96	26	84	51	9	62	31	66	63	73	3.46	+ 0.5	9	3,489	s.	24	nw.	6	17	9	5	3.7	.....	.....
Springfield, Ill.	644	10	91	29.35	30.02	+ .04	75.0	−1.5	101	26	86	54	31	64	28	66	61	66	3.00	+ 0.1	9	4,753	s.	22	ne.	7	9	15	7	5.0	.....	.....
Hannibal	534	74	109	29.46	30.05	+ .05	76.2	−1.2	100	26	87	54	9	66	31	.....	.....	.....	1.19	− 2.6	8	5,521	sw.	27	ne.	7	16	11	4	3.8	.....	.....
St. Louis	567	265	303	29.42	30.02	+ .03	78.4	−0.7	100	26	88	59	31	69	24	67	62	60	0.60	− 2.8	3	7,227	s.	29	s.	23	14	12	.....	4.1	.....	.....
Missouri Valley.							**75.7**	**−0.1**											**64**	**2.35**	**−1.4**										**4.6**		
Columbia, Mo.	781	11	84	29.21	30.02	+ .04	77.2	−0.2	102	27	89	55	1	65	33	.....	.....	.....	0.73	−2.9	8	4,700	s.	25	n.	28	12	18	3	4.4	.....	.....
Kansas City	963	161	181	29.99	29.99	+ .02	78.8	+1.2	102	28	89	60	8	68	32	65	57	51	1.82	−3.0	9	7,134	s.	31	n.	4	18	8	5	3.7	.....	.....
St. Joseph	967	11	49	28.98	29.98	.....	78.6	.....	101	27	90	56	1	67	31	66	60	53	1.61	.....	8	4,659	s.	24	n.	28	17	8	6	3.5	.....	.....
Springfield, Mo.	1,321	98	104	28.65	30.03	+ .05	76.2	−0.2	99	27	86	57	10	67	25	66	60	62	1.11	−3.7	10	5,889	se.	23	n.	29	17	10	4	3.6	.....	.....
Iola	984	11	50	28.99	30.00	+ .03	78.9	+0.8	103	28	92	54	1	66	33	.....	.....	.....	2.48	−1.4	6	4,120	s.	26	s.	24	13	13	5	4.4	.....	.....
Topeka	983	85	101	.....	.....	.....	78.0	+0.4	104	28	90	59	10	66	35	.....	.....	.....	2.65	−2.2	10	6,074	s.	40	n.	28	12	15	4	4.1	.....	.....
Drexel	1,299	10	54	28.62	29.98	.....	75.2	.....	99	27	87	51	8	64	36	67	63	68	2.12	0.0	8	7,013	ne.	37	sw.	3	12	9	10	4.7	.....	.....
Lincoln	1,189	11	84	28.74	29.96	+ .01	77.4	+1.0	101	27	89	53	30	66	37	65	60	59	2.51	−1.3	9	6,250	se.	29	n.	28	12	8	11	4.8	.....	.....
Omaha	1,105	115	122	28.84	29.99	+ .04	77.2	+0.7	99	27	87	56	8	68	31	65	59	58	1.76	−2.6	7	4,970	s.	27	nw.	25	13	11	7	4.5	.....	.....
Valentine	2,598	47	54	27.33	30.00	+ .07	72.8	−0.4	101	2	85	49	1	60	48	63	53	67	2.33	−1.1	10	6,235	s.	36	se.	13	11	15	5	5.1	.....	.....
Sioux City	1,135	94	104	28.89	29.99	+ .04	74.6	+0.4	97	19	85	53	10	64	36	67	64	74	2.08	−1.5	8	6,931	s.	31	s.	3	12	12	7	4.9	.....	.....
Huron	1,306	59	74	28.63	30.01	+ .07	70.0	−1.5	93	20	81	49	10	59	31	64	60	74	6.36	+3.4	10	6,359	se.	37	nw.	24	8	15	8	5.5	.....	.....
Pierre	1,572	70	75	28.34	29.97	+ .04	73.2	−2.0	102	31	85	50	26	61	38	64	59	68	2.04	−0.3	8	6,236	e.	36	ne.	6	12	7	12	6.3	.....	.....
Yankton	1,233	49	57	28.69	29.98	+ .04	73.6	−1.0	98	3	84	51	10	63	35	.....	.....	.....	2.56	−1.0	7	4,398	se.	25	s.	3	9	13	9	5.6	.....	.....

TABLE I.—*Climatological data for Weather Bureau Stations, July, 1918*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.											Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity.	Precipitation.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.						Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F*		°*F*	°*F.*		°*F*	°*F*	°*F.*	*F.*	%	*In.*	*In.*		*Miles*							*0-10*	*In.*	*In.*
Northern Slope.							**67.5**	**−0.6**										**59**	**2.25**	**+0.6**									**4.8**		
Billings	3,140	5					68.2		99	30	84	38	4	53	48				1.63		10		sw.				17	10	4			
Havre	2,505	11	44	27.37	29.97	+ .06	68.0	−0.1	97	19	82	41	23	53	43	56	49	59	0.75	−1.2	9	4,736	e.	36	sw.	12	14	11	6	4.5		
Helena	4,110	87	114	25.84	29.93	+ .03	65.8	−0.8	94	31	78	40	24	53	39	52	43	51	3.18	+2.1	8	5,370	sw.	36	s.	11	9	13	9	5.1		
Kalispell	2,992	11	34	26.93	29.93	.00	64.7	+0.4	92	8	78	39	25	51	40	53	43	54	1.47	+0.6	9	4,279	nw.	28	w.	10	10	18	3	5.0		
Miles City	2,371	26	48	27.50	30.00	+ .08	73.1	+0.2	102	30	85	46	25	61	41	60	52	57	2.19	+0.8	9	4,279	e.	30	n.	20	12	14	5	4.5		
Rapid City	3,259	50	58	26.67	30.02	+ .09	68.9	−1.3	94	31	80	49	26	58	40	59	54	64	4.12	+1.6	18	5,152	n.	34	nw.	24	13	7	11	5.0		
Cheyenne	6,088	84	101	24.14	29.93	+ .06	65.7	−1.7	89	31	73	46	1	53	38	55	49	64	3.90	+1.9	16	6,588	s.	48	ne.	7	7	19	5	5.2		
Lander	5,372	60	68	24.72	29.96	+ .04	67.1	−0.9	96	31	83	44	4	51	43	51	44	54	0.60	−0.3	5	3,403	sw.	26	sw.	23	11	13	7	4.8		
Sheridan	3,790	10	47	26.17	30.01		66.4		95	31	81	45	26	52	45	57	52	67	1.78		11	3,387	nw.	37	nw.	3	11	10	10	5.2		
Yellowstone Park	6,200	11	48		30.00	+ .08	59.6	−1.9	86	30	73	34	4	46	41				2.14	+1.0	15	4,682	s.	36	sw.	6	10	14	7			
North Platte	2,821	11	51	27.14	30.00	+ .07	74.7	+0.8	99	3	87	54	1	63	41	64	60	68	1.88	−0.8	8	4,518	se.	28	ne.	28	17	6	8	4.0		
Middle Slope.							**77.2**	**+0.4**										**58**	**1.69**	**−1.3**									**4.4**		
Denver	5,292	106	113	24.84	29.99	+ .08	71.1	−0.7	94	31	84	54	1	59	36	58	51	60	2.93	+1.3	18	4,596	s.	30	se.	15	14	13	4	4.2		
Pueblo	4,685	80	86	25.38	29.97	+ .06	73.8	−0.4	95	31	87	54	1	60	38	59	52	58	0.93	−1.0	11	3,977	se.	42	w.	24	9	14	8	5.2		
Concordia	1,392	50	58	28.54	29.93	+ .03	78.2	+0.1	103	25	90	57	30	67	32	66	59	57	1.77	−1.8	9	5,939	s.	35	nw.	28	9	16	6	5.0		
Dodge City	2,509	11	51	27.42	29.96	+ .03	78.5	+0.8	99	24	91	54	1	66	33	66	60	61	2.25	−1.1	11	6,010	s.	33	se.	3	16	13	2	3.8		
Wichita	1,358	139	158	28.57	29.96	.00	78.7	−0.3	100	28	89	60	1	68	30	67	61	60	2.11	−1.5	8	8,947	s.	34	se.	22	13	11	7	4.0		
Altus	1,410	5					84.8		108	10	98	62	31	71	37				1.36		7		s.				17	5	9			
Muskogee	652	4					81.0		105	28	95	57	1	67	40				2.88		4		s.				7	2	22			
Oklahoma	1,214	10	47	28.73	29.97	+ .01	82.8	+3.0	103	28	95	62	31	71	34	67	59	51	0.13	−3.5	3	8,230	s.	28	s.	4	14	13	4	4.3		
Southern Slope.							**82.6**	**+2.2**										**49**	**1.09**	**−1.7**									**3.2**		
Abilene	1,738	10	52	28.18	29.92	− .01	87.1	+4.9	106	10	99	68	1	75	31	67	55	40	0.42	−2.0	3	7,643	se.	31	se.	10	16	15	0	3.2		
Amarillo	3,676	10	49	26.34	29.93	+ .06	78.3	+2.2	99	10	91	58	1	65	38	64	57	56	2.23	−0.9	9	7,810	s.	44	s.	1	13	16	2	4.1		
Del Rio	944	64	71	28.97	29.93	+ .03	86.2	+1.5	102	30	95	70	19	76	29				0.23	−2.0	2	7,933	se.	37	nw.	19	25	6	0	1.8		
Roswell	3,566	75	85	26.39	29.93	+ .02	79.0	+0.1	97	3	92	58	6	66	33	63	54	50	1.47	−2.0	8	5,671	s.	46	e.	15	14	15	2	3.7		
Southern Plateau.							**77.9**	**−1.1**										**43**	**1.00**	**−0.2**									**3.2**		
El Paso	3,762	110	133	26.19	29.84	.00	81.0	+0.5	100	3	93	64	15	69	30	63	53	44	1.52	−0.6	13	7,423	se.	50	ne.	19	13	16	2	4.1		
Santa Fe	7,013	57	66	23.38	29.89	+ .01	69.3	+0.6	85	26	80	54	16	58	27	55	47	55	2.42	−0.3	13	4,264	e.	29	se.	31	3	27	1	5.1		
Flagstaff	6,908	8	57	23.47	29.91	+ .08	62.8	−2.2	85	29	76	42	27	49	39				5.47		16		nw.				11	19	1	4.5		
Phoenix	1,108	76	81	28.68	29.79	+ .01	88.3	−2.1	108	30	102	68	14	75	35	69	59	43	1.02	0.0	7	3,796	e.	30	s.	30	16	12	3	3.4		
Yuma	141	9	54	29.62	29.76	.00	90.2	−0.7	111	18	106	64	14	75	40	72	63	46	0.02	−0.1	1	3,819	sw.	35	ne.	6	17	14	0	2.4		
Independence	3,910	11	42	25.94	29.89	+ .06	75.9	−2.6	97	29	91	53	11	61	37	54	36	29	0.04	−0.1	3	4,787	se	24	se.	9	20	8	3	2.6		
Needles	488	4		29.27	29.75		91.8		116	4	109	64	25	75	43				0.77		5						13	9	9	3.2		
Middle Plateau.							**72.0**	**−0.8**										**38**	**0.58**	**+0.1**									**3.3**		
Reno	4,532	74	81	25.47	29.87	.00	69.8	+2.3	94	7	87	45	24	53	43	51	36	35	T.	−0.1	0	6,049	w.	35	w.	22	24	6	1	1.8		
Tonopah	6,090	12	20	24.10	29.88		70.8		89	29	82	48	24	60	27	51	35	30	0.73	+0.4	3	6,827	se.	28	nw.	2	20	9	2	2.5		
Winnemucca	4,344	18	56	25.60	29.90	.00	70.4	−1.2	96	7	88	39	25	53	50	51	34	33	0.27	+0.1	5	4,540	sw.	33	nw.	24	19	7	5	2.9		
Modena	5,479	10	43	24.67	29.90	+ .04	68.8	−0.9	94	30	84	45	23	53	45	51	36	41	0.33	−0.3	9	8,343	sw.	48	s.	24	15	6	10	4.3		
Salt Lake City	4,360	163	203	25.62	29.89	− .01	75.6	−0.6	101	30	87	56	25	64	36	60	51	47	0.76	+0.2	4	5,910	se.	44	n.	24	11	13	7	4.8		
Grand Junction	4,602	82	90	25.43	29.95	+ .08	75.6	−3.6	98	30	89	53	16	62	35	57	45	41	0.78	+0.3	8	4,617	se.	36	sw.	24	14	10	7	4.6		
Northern Plateau.							**72.3**	**+1.6**										**42**	**0.77**	**+0.3**									**4.4**		
Baker	3,471	48	53	26.42	29.94	− .01	66.1	+1.1	95	17	82	38	4	50	43	53	44	52	1.12	+0.7	8	4,512	se.	32	sw.	9	16	7	8	4.4		
Boise	2,739	78	86	27.10	29.93	− .03	74.4	+1.6	102	29	89	46	27	60	42	56	41	37	0.11	−0.1	4	3,944	nw.	35	sw.	31	14	12	5	3.9		
Lewiston	757	40	48	29.11	29.90	− .05	76.5	+2.9	110	18	92	50	4	61	44				0.73	+0.3	4	2,677	e.	26	ne.	14	14	9	8	4.5		
Pocatello	4,477	60	68	25.48	29.90	− .02	71.4	+0.2	97	30	85	47	4	57	40	54	40	40	1.52	+0.9	8	6,244	se.	50	s.	8	11	15	5	4.4		
Spokane	1,929	101	110	27.91	29.91	− .05	71.6	+2.8	101	18	85	48	4	59	40	55	42	42	0.17	−0.5	4	4,193	sw.	38	sw.	9	11	10	10	5.3		
Walla Walla	991	57	65	28.85	29.90	− .07	75.1	+1.0	108	17	89	49	4	61	41	58	45	39	0.96	+0.6	5	3,430	s.	22	s.	9	16	9	6	4.2		
North Pacific Coast Region.							**62.0**	**0.0**										**74**	**0.98**	**+0.3**									**5.6**		
North Head	211	11	53	29.82	30.05	− .03	56.4	−1.3	68	22	59	46	4	54	10	55	54	93	0.67	+0.1	11	10,328	nw.	44	nw.	8	4	12	15	7.1		
North Yakima	1,071	4					73.0		106	17	88	46	27	58	42				0.28		4		nw.				23	5	3			
Port Angeles	29	8	53	30.02	30.06		56.8		75	17	65	46	4	49	33				0.81	+0.4	5	4,378	nw.	21	nw.	5	8	14	9	5.8		
Seattle	125	215	250	29.90	30.03	− .01	63.0	−0.5	83	17	71	47	3	55	24	56	51	70	1.38	+0.7	8	6,074	n.	27	sw.	18	8	14	9	5.4		
Tacoma	213	113	120	29.80	30.02	− .04	63.8	+0.4	83	31	74	47	3	54	27	56	51	68	0.75	+0.1	7	4,074	n.	20	n.	4	2	16	13	6.7		
Tatoosh Island	199	7	57	29.94	30.04	− .01	54.0	−1.1	66	13	58	45	4	50	18	52	51	93	1.60	−0.2	12	8,251	s.	46	s.	17	5	12	14	6.6		
Medford	1,425	4					70.0		98	1	88	43	27	51	55				0.03		1		nw.				18	7	6			
Portland, Oreg	153	68	106	29.83	29.99	− .06	67.8	+1.5	91	28	78	48	3	57	34	58	52	62	1.08	+0.5	5	4,063	nw.	21	nw.	22	12	10	9	5.2		
Roseburg	510	9	57	29.46	30.01	− .02	67.0	+0.9	93	28	82	43	3	52	42	56	48	60	0.57	+0.2	4	2,426	n.	16	w.	16	17	13	1	2.6		
Middle Pacific Coast Region.							**64.4**	**−1.1**										**59**	**0.04**	**0.0**									**3.3**		
Eureka	62	73	89	29.98	30.05	.00	55.4	+0.1	67	15	60	48	14	51	15	53	51	89	0.22	+0.1	3	4,424	n.	26	n.	26	2	10	19	7.6		
Mount Tamalpais	2,375	11	18	27.52	29.95	.00	66.0	−4.5	87	7	75	43	9	57	27	52	40	42	0.00	0.0	0	10,196	nw.	55	nw.	23	28	3	0	1.2		
Point Reyes Light	490	7	18	29.42	29.94		53.5	−0.2	64	2	58	46	7	49	14				T.		0	10,861	nw.	61	nw.	21	2	9	20	7.8		
Red Bluff	332	50	58	29.51	29.85	− .04	79.3	−2.8	103	7	94	55	14	64	38	59	42	32	0.00	0.0	0	3,696	se.	19	se.	22	31	0	0	0.6		
Sacramento	69	106	117	29.81	29.88	.00	72.2	−0.3	103	7	89	50	5	55	45	58	48	51	0.00	0.0	0	6,965	s.	28	sw.	22	29	2	0	0.5		
San Francisco	155	209	213	29.79	29.96	+ .01	58.8	+1.5	75	20	65	49	7	52	24	54	52	84	T.	0.0	0	9,735	sw.	34	sw.	11	17	11	3	3.5		
San Jose	141	12	110	29.82	29.97		65.5	−1.4	93	21	79	46	11	52	36			0	0.0	0	4,760	nw.	24	se.	27	29	2	0	1.6		
South Pacific Coast Region.							**70.6**	**+0.7**										**66**	**0.02**	**0.0**									**2.7**		
Fresno	327	89	98	29.51	29.83	+ .03	79.9	−2.1	104	30	96	56	23	64	38	60	44	34	T.	0.0	0	6,928	nw.	24	nw.	22	27	4	0	1.0		
Los Angeles	338	159	191	29.56	29.92	+ .02	69.9	+2.5	91	19	79	58	11	61	28	62	58	73	0.09	+0.1	1	3,737	sw.	15	s.	24	15	14	2	3.6		
San Diego	87	62	70	29.82	29.92	.00	68.0	+1.1	79	18	73	61	12	63	14	63	61	82	T.	0.0	0	4,864	nw.	20	nw.	18	21	10	0	3.2		
San Luis Obispo	201	32	40	29.74	29.96	+ .01	64.4	+1.2	85	19	76	48	24	53	33	56	52	75	T.	0.0	0	2,973	nw.	15	w.	23	23	8	0	2.8		
West Indies.																																	
San Juan, P. R.	82	8	54	29.94	30.03	+ .04	79.5		85	30	84	71	28	75	13				5.71	−0.7	19	10,791	e.	33	e.	6	10	14	7	5.2		
Panama Canal.																																	
Balboa Heights	118	7	97	29.69	29.81	− .03	81.6	+1.3	91	5	88	73	2	275	16	76	75	88	5.13	−2.7	13	5,618	nw.	28	nw.	8	0	21	10	6.8		
Colon	36	30	97	29.78	29.81	− .04	80.2	+0.3	86	25	84	70	18	76	15	77	76	87	10.36	−5.7	25	7,199	n.	32	sw.	18	0	6	25	8.4		
Alaska.																																	
Juneau	80	11	49				59.7		83	14	60	41	1	50	35	55	51	76	2.30		11	2,595	s.	15	w.	29	12	4	15	5.6		

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during July, 1918, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex	13			0.37														0.35			
Albany, N. Y	1			0.87														0.46			
Alpena, Mich	2			0.56														0.47			
Amarillo, Tex	30	7:55 p. m.	8:46 a. m.	0.74	8:02 a. m.	8:25 a. m.	T.	†0.05	†0.14	†0.45	†0.62	†0.73									
Anniston, Ala	20	2:33 p. m.	3:43 p. m.	0.85	2:44 p. m.	3:00 p. m.	0.04	0.25	0.49	0.63	0.67										
	25	7:28 p. m.	9:00 p. m.	0.76	7:35 p. m.	7:46 p. m.	0.05	0.30	0.59	0.62											
	30	6:02 p. m.	8:45 p. m.	1.83	6:07 p. m.	6:54 p. m.	0.01	0.12	0.17	0.22	0.36	0.63	0.88	1.18	1.41	1.56	1.62				
Asheville, N. C	22	5:10 p. m.	5:50 p. m.	0.59	5:25 p. m.	5:46 p. m.	0.02	0.17	0.31	0.42	0.55	0.57									
Atlanta, Ga	8	5:35 p. m.	7:15 p. m.	0.72	5:52 p. m.	6:03 p. m.	0.01	0.36	0.70												
Atlantic City, N. J	31			1.24														0.23			
Augusta, Ga	8	3:00 p. m.	7:15 p. m.	1.09	3:19 p. m.	3:57 p. m.	0.01	0.20	0.37	0.53	0.46	0.76	0.81	0.89	0.92						
	23	4:30 p. m.	7:35 p. m.	0.73	4:46 p. m.	5:03 p. m.	0.01	0.06	0.25	0.53	0.60										
Baker, Oreg	15			0.37														0.34			
Baltimore, Md	30			0.60														0.52			
Bentonville, Ark	16			0.32														0.19			
Binghamton, N. Y	1	1:30 a. m.	6:45 a. m.	1.12	5:46 a. m.	6:15 a. m.	0.42	0.07	0.24	0.42	0.53	0.59	0.64								
	11	2:50 p. m.	4:30 p. m.	0.55	3:14 p. m.	3:31 p. m.	0.01	0.20	0.40	0.50	0.53										
	24	1:40 p. m.	5:20 p. m.	1.26	2:10 p. m.	2:35 p. m.	0.02	0.11	0.40	0.69	0.92	1.03									
Birmingham, Ala	18	8:35 a. m.	10:25 a. m.	1.16	9:22 a. m.	10:08 a. m.	0.18	0.10	0.24	0.39	0.48	0.58	0.67	0.71	0.81	0.94	0.96				
Bismarck, N. Dak	23			0.49														0.36			
Block Island, R. I	31			1.00														0.27			
Boise, Idaho	9			0.06														0.06			
Boston, Mass	12			0.39														0.39			
Buffalo, N. Y	29			0.59														0.51			
Burlington, Vt	6	4:15 p. m.	5:45 p. m.	0.78	4:18 p. m.	4:50 p. m.	0.01	0.15	0.36	0.42	0.50	0.54	0.59	0.65							
Cairo, Ill	21			0.43														0.42			
Canton, N. Y	29			0.99														0.34			
Charles City, Iowa	25–26	7:44 p. m.	4:35 a. m.	3.62	7:56 p. m.	8:31 p. m.	0.03	0.05	0.17	0.32	0.62	0.90	1.03	1.09							
					2:19 a. m.	3:26 a. m.	1.94	0.11	0.14	0.28	0.44	0.55	0.68	0.76	0.77	0.84	1.04	1.18	1.54		
Charleston, S. C	8	1:45 p. m.	D. N. a. m.	2.64	2:36 p. m.	3:24 p. m.	0.33	0.10	0.18	0.31	0.50	0.70	0.71	0.71	0.75	0.95	0.98				
					5:31 p. m.	6:21 p. m.	0.03	0.13	0.16	0.17	0.26	0.46	0.58	0.78	0.95	1.01	1.15				
	19	5:05 p. m.	D. N. p. m.	2.70	6:21 p. m.	7:11 p. m.	.....	1.24	1.27	1.33	1.42	1.56	1.60	1.61	1.65	1.68	1.78				
					7:11 p. m.	7:51 p. m.	.....	1.92	2.04	2.13	2.19	2.28	2.40	2.54	2.60						
Charlotte, N. C	8			0.58														0.39			
Chattanooga, Tenn	30	6:42 a. m.	1:49 p. m.	2.24	7:31 a. m.	8:36 a. m.	0.11	0.05	0.11	0.21	0.38	0.57	0.79	1.00	1.27	1.51	1.64	1.74	1.85		
Cheyenne, Wyo	18	5:55 p. m.	7:10 p. m.	0.83	6:04 p. m.	6:24 p. m.	0.01	0.17	0.40	0.60	0.67										
Chicago, Ill	28	3:56 p. m.	6:43 p. m.	0.61	4:09 p. m.	8:21 p. m.	0.01	0.23	0.47	0.53											
Cincinnati, Ohio	28	5:45 p. m.	6:31 p. m.	0.87	5:45 p. m.	6:15 p. m.	0.00	0.20	0.31	0.43	0.60	0.73	0.80								
Cleveland, Ohio	23			0.40														0.39			
Columbia, Mo	24			0.25														0.16			
Columbia, S. C	19			0.59														0.47			
Columbus, Ohio	23	6:03 p. m.	7:50 p. m.	0.94	6:21 p. m.	6:56 p. m.	0.01	0.13	0.34	0.48	0.60	0.71	0.85	0.92							
Concord, N. H	17			0.51														0.22			
Concordia, Kans	18	12:57 p. m.	1:26 p. m.	0.62	1:01 p. m.	1:18 p. m.	0.01	0.13	0.35	0.55	0.61										
Corpus Christi, Tex	28			0.16														0.10			
Dallas, Tex	2			0.78														0.50			
Davenport, Iowa	6	6:38 p. m.	8:50 p. m.	1.55	7:05 p. m.	7:25 p. m.	0.13	0.16	0.46	0.84	1.13										
	7	1:55 p. m.	3:35 p. m.	0.65	2:22 p. m.	2:34 p. m.	0.01	0.25	0.48	0.54											
Dayton, Ohio	22	2:46 p. m.	4:15 p. m.	1.05	2:55 p. m.	3:40 p. m.	0.05	0.15	0.39	0.50	0.61	0.64	0.68	0.73	0.82	0.91					
Del Rio, Tex	19			0.16														0.08			
Denver, Colo	17			0.40														0.40			
Des Moines, Iowa	4			0.74														0.30			
Detroit, Mich	2			0.53														0.45			
Devils Lake, N. Dak	27			0.67														0.45			
Dodge City, Kans	15			0.83														0.28			
Drexel, Nebr	17	D. N. a. m.	3:25 p. m.	1.47	5:02 a. m.	6:04 a. m.	0.04	0.06	0.14	0.28	0.38	0.41	0.46	0.49	0.54	0.66	0.75	0.84	0.85		
Dubuque, Iowa	25			0.51														0.37			
Duluth, Minn	28			0.35														0.14			
Eastport, Me	14			0.34														0.24			
Elkins, W. Va	13			0.25														0.24			
Ellendale, N. Dak	27	6:05 p. m.	7:03 p. m.	0.73	6:15 p. m.	6:40 p. m.	0.01	0.13	0.32	0.52	0.63	0.68									
El Paso, Tex	26			0.40														0.36			
Erie, Pa	28	5:05 p. m.	6:32 p. m.	0.66	5:07 p. m.	5:27 p. m.	0.01	0.18	0.31	0.53	0.59										
	29	3:49 p. m.	10:40 p. m.	3.19	3:57 p. m.	5:42 p. m.	0.01	0.17	0.42	0.63	0.87	1.25	1.55	1.72	1.78	1.83	1.97	2.07	2.25	2.51	2.62
Escanaba, Mich	22			0.40														0.36			
Eureka, Cal	14			0.14														0.09			
Evansville, Ind	29			0.76														0.46			
Flagstaff, Ariz	21			1.20		*												*			
Fort Smith, Ark	11			0.46														0.17			
Fort Wayne, Ind	27			0.28														0.28			
Fort Worth, Tex	2			0.60														0.26			
Fresno, Cal	31			T.														T.			
Galveston, Tex	2	2:25 p. m.	8:30 p. m.	1.93	2:49 p. m.	3:22 p. m.	0.02	0.13	0.38	0.61	0.79	1.05	1.32	1.39							
Grand Haven, Mich	24	9:20 p. m.	D. N. a. m.	1.34	10:21 p. m.	10:38 p. m.	0.37	0.16	0.39	0.54	0.59										
Grand Junction, Colo	9			0.32														0.16			
Grand Rapids, Mich	25			0.61														0.29			
Green Bay, Wis	4			0.71														0.33			
Greenville, S. C	21			0.97														0.59			
Hannibal, Mo	24			0.31														0.23			
Harrisburg, Pa	24–25	4:50 p. m.	D. N. a. m.	2.25	5:05 p. m.	6:38 p. m.	0.03	0.08	0.13	0.28	0.40	0.49	0.64	0.73	0.84	0.84	0.90	0.98	1.40	1.61	
Hartford, Conn	13			0.56														0.39			
Hatteras, N. C	12	3:25 p. m.	5:45 p. m.	0.71	3:27 p. m.	3:43 p. m.	0.01	0.15	0.33	0.50	0.52										
	19	7:05 p. m.	D. N. a. m.	1.20	8:32 p. m.	8:59 p. m.	0.17	0.11	0.20	0.28	0.55	0.61	0.66								
	30	7:05 a. m.	4:30 p. m.	1.79	2:09 p. m.	3:38 p. m.	0.52	0.07	0.12	0.18	0.26	0.36	0.44	0.51	0.55	0.56	0.62	0.85	1.02	1.18	
Havre, Mont	26			0.15														0.12			
Helena, Mont	19			0.39														0.35			
Houghton, Mich	24			0.37														*			
Houston, Tex	2	1:38 p. m.	6:40 p. m.	4.36	1:54 p. m.	2:44 p. m.	0.03	0.15	0.47	0.89	1.05	1.12	1.22	1.47	1.77	1.98	2.07				
					2:44 p. m.	3:34 p. m.		2.16	2.26	2.49	2.73	2.78	3.00	3.21	3.40	3.56	3.66				
					3:34 p. m.	4:04 p. m.		3.76	3.86	3.93	4.00	4.06	4.13								
	17	2:23 p. m.	3:55 p. m.	0.80	3:15 p. m.	3:41 p. m.	0.01	0.14	0.43	0.61	0.73	0.77									
Huron, S. Dak	6	6:05 a. m.	1:00 p. m.	1.72	6:53 a. m.	7:38 a. m.	0.02	0.08	0.18	0.39	0.58	0.76	0.87	0.97	1.05	1.15	1.18				
	24	4:15 p. m.	6:25 p. m.	1.62	5:06 p. m.	5:41 p. m.	0.18	0.08	0.19	0.43	0.73	1.02	1.22	1.27							
Independence, Cal	18			0.02														*			
Indianapolis, Ind	26–27	5:14 p. m.	2:30 a. m.	1.59	6:04 p. m.	6:29 p. m.	0.04	0.09	0.24	0.37	0.51	0.56									
Iola, Kans	16	4:55 p. m.	9:00 p. m.	0.62	5:10 p. m.	5:28 p. m.	0.02	0.19	0.37	0.48	0.52										
Jacksonville, Fla	21	1:54 p. m.	7:35 p. m.	1.69	2:05 p. m.	3:13 p. m.	0.01	0.10	0.46	0.76	0.78	0.78	0.78	0.78	0.78	0.79	0.92	1.22	1.43		
Kalispell, Mont	26			0.59														0.21			
Kansas City, Mo	28			0.47														0.22			
Keokuk, Iowa	24			0.27														0.17			

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during July, 1918, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Key West, Fla.	4			0.43														0.41			
Knoxville, Tenn.	8			0.46														0.28			
La Crosse, Wis.	24	8:20 a. m.	2:05 p. m.	1.35	1:14 p. m.	1:42 p. m.	0.37	0.08	0.15	0.32	0.74	0.90	0.97								
Lander, Wyo.	8			0.37														0.23			
Lansing, Mich.	26–27	7:07 p. m.	D. N. a. m.	0.97	7:14 p. m.	7:32 p. m.	0.02	0.24	0.35	0.45	0.50										
Lewiston, Idaho.	23			0.49														0.19			
Lexington, Ky.	24			0.32														0.26			
Lincoln, Nebr.	17			1.55														0.69			
Little Rock, Ark.	29			0.57														0.33			
Los Angeles, Cal.	1			0.09														0.09			
Louisville, Ky.	29	1:35 p. m.	2:40 p. m.	1.81	1:42 p. m.	2:16 p. m.	0.02	0.27	0.54	0.82	1.12	1.43	1.71	1.76							
Ludington, Mich.	28–29			0.64														0.41			
Lynchburg, Va.	12	11:55 a. m.	12:45 p. m.	1.04	12:11 p. m.	12:29 p. m.	0.01	0.25	0.70	0.92	1.00										
	16	3:45 p. m.	5:00 p. m.	0.58	4:07 p. m.	4:20 p. m.	0.01	0.22	0.46	0.53											
Macon, Ga.	23	4:34 p. m.	6:02 p. m.	1.00	4:49 p. m.	5:11 p. m.	0.14	0.25	0.55	0.66	0.73	0.75									
Madison, Wis.	28			0.52														0.46			
Marquette, Mich.	15	12:45 p. m.	4:00 p. m.	1.18	1:57 p. m.	2:47 p. m.	0.73	*	*	*	0.42	0.47	0.56	0.57	0.67	0.73	0.73				
Memphis, Tenn.	27–28	D. N. p. m.	D. N. a. m.	0.67	11:45 p. m.	12:00 a. m.	0.02	0.08	0.29	0.41	0.56	0.64									
Meridian, Miss.	27			0.18														0.18			
Miami, Fla.	17	5:18 p. m.	6:35 p. m.	0.86	5:23 p. m.	5:43 p. m.	0.01	0.16	0.38	0.65	0.80										
Milwaukee, Wis.	9			0.22														0.22			
Minneapolis, Minn.	24	5:50 a. m.	7:10 a. m.	1.10	6:23 a. m.	6:49 a. m.	0.03	0.20	0.39	0.61	0.88	1.00	1.04								
Mobile, Ala.	18			0.46														0.42			
Modena, Utah.	13			0.22														0.15			
Montgomery, Ala.	25	5:37 p. m.	7:54 p. m.	0.87	6:28 p. m.	6:54 p. m.	0.05	0.08	0.14	0.31	0.67	0.77	0.80								
Moorhead, Minn.	1	4:10 p. m.	5:11 p. m.	0.98	4:32 p. m.	5:10 p. m.	0.01	0.14	0.29	0.51	0.70	0.77	0.84	0.92	0.97						
Mount Tamalpais, Cal.	‡			‡														‡			
Nantucket, Mass.	7			0.36														0.36			
Nashville, Tenn.	29	3:55 p. m.	6:40 p. m.	1.13	4:00 p. m.	4:35 p. m.	0.01	0.25	0.53	0.66	0.77	0.82	0.91	0.97							
New Haven, Conn.	17	12:56 p. m.	4:09 p. m.	0.82	12:59 p. m.	1:33 p. m.	T.	0.20	0.40	0.53	0.58	0.67	0.72	0.77							
	30–31	3:30 p. m.	8:15 a. m.	2.78	4:05 p. m.	4:51 p. m.	0.17	0.17	0.34	0.46	0.57	0.60	0.66	0.74	0.80	0.87	0.90				
New Orleans, La.	20	11:21 a. m.	1:47 p. m.	1.01	11:27 a. m.	11:47 a. m.	0.01	0.12	0.44	0.75	0.85										
New York, N. Y.	30–31	5:10 p. m.	3:00 a. m.	2.48	11:40 p. m.	12:10 a. m.	1.28	0.07	0.18	0.31	0.42	0.48	0.54								
Norfolk, Va.	1			0.61														0.47			
Northfield, Vt.	30			0.46														0.45			
North Head, Wash.	26			0.09														0.09			
North Platte, Nebr.	22			0.39														0.39			
Oklahoma, Okla.	17			0.05														0.05			
Omaha, Nebr.	17			1.26														0.60			
Oswego, N. Y.	1			0.71														0.55			
Palestine, Tex.	2			0.21														0.08			
Parkersburg, W. Va.	25			0.29														0.25			
Pensacola, Fla.	1	11:17 a. m.	4:45 p. m.	2.37	12:39 p. m.	1:24 p. m.	0.64	0.11	0.33	0.34	0.35	0.40	0.47	0.61	0.93	1.20					
	19	1:10 a. m.	2:30 a. m.	1.07	1:15 a. m.	2:13 a. m.	0.01	0.09	0.17	0.32	0.44	0.45	0.47	0.52	0.57	0.73	0.91	1.05			
	20	5:40 a. m.	6:52 a. m.	0.59	6:06 a. m.	6:19 a. m.	0.02	0.20	0.42	0.53											
Peoria, Ill.	7			1.72														0.60			
Philadelphia, Pa.	19	3:10 p. m.	4:40 p. m.	0.81	3:25 p. m.	4:02 p. m.	0.01	0.05	0.17	0.35	0.49	0.51	0.67	0.73							
Phoenix, Ariz.	2			0.51														0.44			
Pierre, S. Dak.	14			0.88														0.40			
Pittsburgh, Pa.	29			1.08														0.70			
Pocatello, Idaho.	5			0.26														0.26			
Point Reyes Light, Cal.	13			0.00														T.			
Port Angeles, Wash.	9			0.30														0.12			
Port Huron, Mich.	29			0.19														0.19			
Portland, Me.	30			0.80														0.52			
Portland, Oreg.	23			0.83														0.20			
Providence, R. I.	12	4:35 p. m.	8:10 p. m.	1.72	4:47 p. m.	5:31 p. m.	0.01	0.31	0.61	0.82	0.93	1.15	1.38	1.53	1.61						
Pueblo, Colo.	21			0.20														0.13			
Raleigh, N. C.	18–19	6:06 p. m.	D. N. a. m.	1.44	1:44 a. m.	2:44 a. m.	0.43	0.05	0.15	0.10	0.24	0.40	0.50	0.55	0.60	0.68	0.86	1.00			
Rapid City, S. Dak.	13			1.53														0.52			
Reading, Pa.	19			0.45														0.45			
Red Bluff, Cal.	‡			‡														‡			
Reno, Nev.	30			T.														T.			
Richmond, Va.	29			0.30														0.29			
Rochester, N. Y.	29	7:15 p. m.	11:50 p. m.	0.71	7:39 p. m.	7:59 p. m.	0.05	0.27	0.39	0.45	0.50										
Roseburg, Oreg.	23			0.31														0.13			
Roswell, N. Mex.	13			0.39														0.39			
Sacramento, Cal.	‡			‡														‡			
Saginaw, Mich.	26	4:19 p. m.	5:33 p. m.	0.68	4:30 p. m.	4:49 p. m.	0.02	0.21	0.41	0.55	0.65										
St. Joseph, Mo.	4			0.75														0.40			
St. Louis, Mo.	24			0.36														0.20			
St. Paul, Minn.	14	6:45 p. m.	11:15 p. m.	1.08	7:02 p. m.	7:47 p. m.	0.02	0.10	0.23	0.34	0.44	0.55	0.62	0.74	0.79	0.85					
	24	6:07 a. m.	7:28 a. m.	1.60	6:21 a. m.	7:03 a. m.	0.02	0.16	0.44	0.64	0.84	1.10	1.31	1.40	1.51	1.56					
Salt Lake City, Utah.	9			0.31														0.31			
San Antonio, Tex.	30			1.09														0.48			
San Diego, Cal.	1			T.														T.			
Sand Key, Fla.	1			0.42														0.42			
Sandusky, Ohio.	26	11:15 a. m.	1:15 p. m.	0.95	1:03 p. m.	1:31 p. m.	0.01	0.35	0.61	0.69	0.75	0.87	0.92								
Sandy Hook, N. J.	30–31			3.73														0.70			
San Francisco, Cal.	15			T.														T.			
San Jose, Cal.	‡			‡														‡			
San Luis Obispo, Cal.	1			T.														T.			
Santa Fe, N. Mex.	2	5:15 p. m.	6:20 p. m.	0.61	5:25 p. m.	5:58 p. m.	T.	0.10	0.17	0.21	0.27	0.36	0.55	0.60							
	27	2:53 p. m.	5:15 p. m.	0.64	3:26 p. m.	3:36 p. m.	0.08	0.24	0.47	0.51	0.52	0.57	0.59								
Sault Ste. Marie, Mich.	23	12:30 a. m.	7:15 a. m.	1.13	2:53 a. m.	3:52 a. m.	0.29	0.35	0.44	0.49	0.54	0.57	0.62	0.66	0.71	0.75	0.82				
Savannah, Ga.	20	1:05 p. m.	5:40 p. m.	1.09	1:25 p. m.	1:45 p. m.	0.04	0.07	0.21	0.49	0.63										
	29	11:01 a. m.	12:03 p. m.	0.56	11:23 a. m.	11:39 a. m.	0.01	0.18	0.37	0.51	0.54										
	31	1:27 p. m.	6:45 p. m.	3.74	2:45 p. m.	3:48 p. m.	0.62	0.08	0.23	0.44	0.71	0.87	1.19	1.62	2.04	2.32	2.41	2.56	2.65		
Scranton, Pa.	24	12:42 p. m.	7:30 p. m.	1.11	5:04 p. m.	5:31 p. m.	0.37	0.05	0.12	0.21	0.42	0.57	0.62								
Seattle, Wash.	9			0.36														0.19			
Sheridan, Wyo.	16			0.48														0.48			
Shreveport, La.	1			T.														T.			
Sioux City, Iowa.	25–26	9:28 p. m.	D. N. a. m.	0.70	10:10 p. m.	10:42 p. m.	0.03	0.06	0.21	0.29	0.34	0.40	0.48	0.51							
Spokane, Wash.	23			0.13														0.07			
Springfield, Ill.	6–7	9:00 p. m.	6:33 a. m.	1.69	4:48 a. m.	5:17 a. m.	0.68	0.12	0.21	0.25	0.40	0.71	0.85								
Springfield, Mo.	29			0.48														0.23			
Syracuse, N. Y.	27			0.44														0.44			
Tacoma, Wash.	10			0.26														0.11			
Tampa, Fla.	6	12:45 p. m.	2:20 p. m.	0.71	1:29 p. m.	2:05 p. m.	0.04	0.10	0.30	0.43	0.48	0.50	0.58	0.64	0.66						
	10	1:34 p. m.	3:15 p. m.	1.08	1:42 p. m.	2:23 p. m.	0.01	0.24	0.47	0.64	0.67	0.67	0.67	0.78	0.91	0.93					

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during July, 1918, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Tatoosh Island, Wash	20			0.31														0.23			
Taylor, Tex	30			0.07														0.06			
Terre Haute, Ind	28			0.40														0.40			
Thomasville, Ga	18			1.03														0.56			
Toledo, Ohio	22			0.44														0.39			
Tonopah, Nev	8			0.46														0.40			
Topeka, Kans	23–24	11:44 p. m.	2:40 a. m.	1.13	11:47 p. m.	12:17 a. m.	0.01	0.16	0.23	0.30	0.43	0.53	0.61								
Trenton, N. J	6	7:14 p. m.	7:30 p. m.	0.81	7:55 p. m.	8:18 p. m.	0.03	0.08	0.25	0.59	0.73	0.78									
	30	4:00 p. m.	D. N. a. m.	2.88	4:37 p. m.	5:45 p. m.	0.12	0.26	0.47	0.52	0.53	0.58	0.62	0.68	0.84	0.97	1.03	1.30	1.44		
Valentine, Nebr	12			0.85														0.56			
Vicksburg, Miss	18	3:40 p. m.	5:45 p. m.	0.97	4:23 p. m.	5:17 p. m.	0.01	0.08	0.19	0.37	0.43	0.46	0.47	0.48	0.49	0.61	0.79	0.89			
	30	3:30 p. m.	4:10 p. m.	0.56	3:43 p. m.	3:57 p. m.	0.01	0.31	0.46	0.54											
Walla Walla, Wash	23			0.51														0.31			
Washington, D. C	12–13	4:15 p. m.	5:00 a. m.	1.19	5:21 p. m.	5:50 p. m.	0.01	0.19	0.36	0.52	0.63	0.73	0.79								
	25	1:26 p. m.	3:12 p. m.	1.08	1:48 p. m.	2:17 p. m.	0.03	0.06	0.13	0.29	0.56	0.72	0.83								
Wausau, Wis	24	6:22 a. m.	9:48 a. m.	0.75	7:17 a. m.	7:42 a. m.	0.07	0.11	0.29	0.40	0.45	0.54									
	28	5:23 a. m.	10:55 a. m.	1.27	6:04 a. m.	6:44 a. m.	0.01	0.10	0.31	0.51	0.60	0.67	0.70	0.75	0.81						
Wichita, Kans	17			0.75														0.49			
Williston, N. Dak	6			0.55														0.32			
Wilmington, N. C	19–20	8:10 p. m.	D. N. a. m.	1.62	7:26 p. m.	10:00 p. m.	0.04	0.16	0.37	0.57	0.82	1.05	1.32	1.46							
	30	7:20 p. m.	10:15 p. m.	1.14	7:28 p. m.	8:03 p. m.	0.01	0.18	0.38	0.43	0.49	0.57	0.83	0.96							
Winnemucca, Nev	9			0.13														0.08			
Wytheville, Va	30	11:47 a. m.	D. N. p. m.	2.03	11:51 a. m.	12:56 p. m.	0.01	0.09	0.13	0.28	0.43	0.58	0.81	1.04	1.25	1.35	1.51	1.66	1.78		
Yankton, S. Dak	14	5:15 a. m.	9:30 a. m.	1.34	6:57 a. m.	7:09 a. m.	0.39	0.31	0.57	0.65											
Yellowstone Park, Wyo	5			0.47														0.19			

TABLE III.—*Data furnished by the Canadian Meteorological Service, July, 1918.*

Stations.	Altitude above M. S. L.* Jan. 1916.	Pressure.			Temperature.						Precipitation.		
		Station reduced to mean of 24 hours.	Sea-level reduced to mean of 24 hours.	Departure from normal.	Mean max.+ mean min.÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Feet.	*Inches.*	*Inches.*	*Inches.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F	125	29.94	30.08	+0.11	53.3	−6.0	61.2	45.4	78	39	2.25	−1.64	.....
Sydney, C. B. I	48	30.01	30.05	+ .12	62.8	+0.5	72.4	53.2	86	44	3.72	+0.07	.....
Halifax, N. S	88	29.91	30.01	+ .05	63.2	−0.2	70.6	55.8	88	46	5.91	+1.86	.....
Yarmouth, N. S	65	29.90	29.97	+ .02	61.5	+2.0	69.0	54.0	78	50	5.92	+2.30	.....
Charlottetown, P. E. I	38	29.95	29.99	+ .09	65.3	+1.2	73.0	57.6	84	46	3.62	+0.13	.....
Chatham, N. B	28	29.96	29.98	+ .10	65.6	+0.6	73.6	57.5	94	48	9.62	+5.43	.....
Father Point, Que	20	29.95	29.97	+ .12	56.3	−1.3	63.2	48.5	74	42	4.05	+1.01	.....
Quebec, Que	296	29.63	29.95	+ .04	66.6	+1.1	75.1	58.1	88	49	7.98	+3.72	.....
Montreal, Que	187	29.74	29.94	+ .01	70.5	+2.0	79.2	61.8	92	50	3.61	−0.68	.....
Stonecliffe, Ont	489	29.34	29.94	.00	67.2	+1.6	79.3	55.2	96	46	1.75	−1.37	.....
Ottawa, Ont	236	29.68	29.94	.00	69.6	+0.1	80.6	58.8	94	48	3.60	+0.13	.....
Kingston, Ont	285	29.66	29.96	− .01	67.8	−0.4	76.3	59.3	90	50	2.58	−0.31	.....
Toronto, Ont	379	29.58	29.97	.00	69.6	+1.6	80.5	58.8	92	48	2.32	−0.60	.....
White River, Ont	1,244	28.68	29.97	+ .03	58.2	−1.3	73.8	42.7	88	29	2.77	−0.03	.....
Port Stanley, Ont	592	29.38	30.01	+ .03	66.6	−1.2	76.9	56.3	86	44	0.88	−2.16	.....
Southampton, Ont	656	29.29	.....	.....	64.0	−0.7	73.5	54.4	89	41	1.07	−0.91	.....
Parry Sound, Ont	688	29.30	29.98	+ .02	68.3	+2.3	80.0	56.7	97	43	1.03	−1.59	.....
Port Arthur, Ont	644	29.31	30.02	+ .08	61.6	−0.4	71.8	51.5	80	39	1.77	−1.71	.....
Winnepeg, Man	760	29.17	30.00	+ .07	63.7	−2.3	76.6	50.9	90	40	1.99	−1.09	.....
Minnedosa, Man	1,690	28.22	30.01	+ .08	61.8	−0.4	76.3	47.4	92	36	2.38	−0.22	.....
Qu'Appelle, Sask	2,115	27.76	29.98	+ .06	62.2	−1.3	75.8	48.6	99	30	2.52	+0.04	.....
Medicine Hat, Alberta	2,144	27.67	29.90	.00	69.1	+1.3	84.6	53.7	98	42	1.78	−0.31	.....
Swift Current, Sask	2,392	27.42	29.94	+ .03	66.1	−0.4	81.7	50.5	97	33	1.22	−1.22	.....
Calgary, Alberta	3,428	26.49	29.96	+ .06	63.7	+3.1	80.1	47.3	94	32	1.35	−1.33	0.1
Banff, Alberta	4,521	25.45	29.95	+ .05	58.8	+2.2	75.1	42.6	91	32	1.56	−1.68	3.0
Edmonton, Alberta	2,150	27.70	29.95	+ .05	60.6	0.0	73.8	47.5	90	29	2.67	−0.36	.....
Prince Albert, Sask	1,450	28.46	30.00	+ .09	61.5	−0.4	75.3	47.8	92	33	1.26	−0.79	.....
Battleford, Sask	1,592	28.26	29.98	+ .08	63.5	−1.2	78.7	48.3	97	32	1.22	−1.12	.....
Kamloops, B. C	1,262	28.71	29.97	+ .03	70.8	+2.3	84.5	57.2	102	47	1.23	−0.38	.....
Victoria, B. C	230	29.75	30.00	+ .05	58.9	−1.1	66.6	51.2	78	46	0.48	+0.08	.....
Barkerville, B. C	4,180	25.77	30.04	+ .13	55.3	+0.2	67.3	43.3	84	28	2.43	−0.59	.....
Hamilton, Bermuda	151	29.98	30.14	.00	76.6	−2.1	81.1	72.1	84	68	4.54	+0.10	.....

Chart I. Hydrographs of Several Principal Rivers, July, 1918.

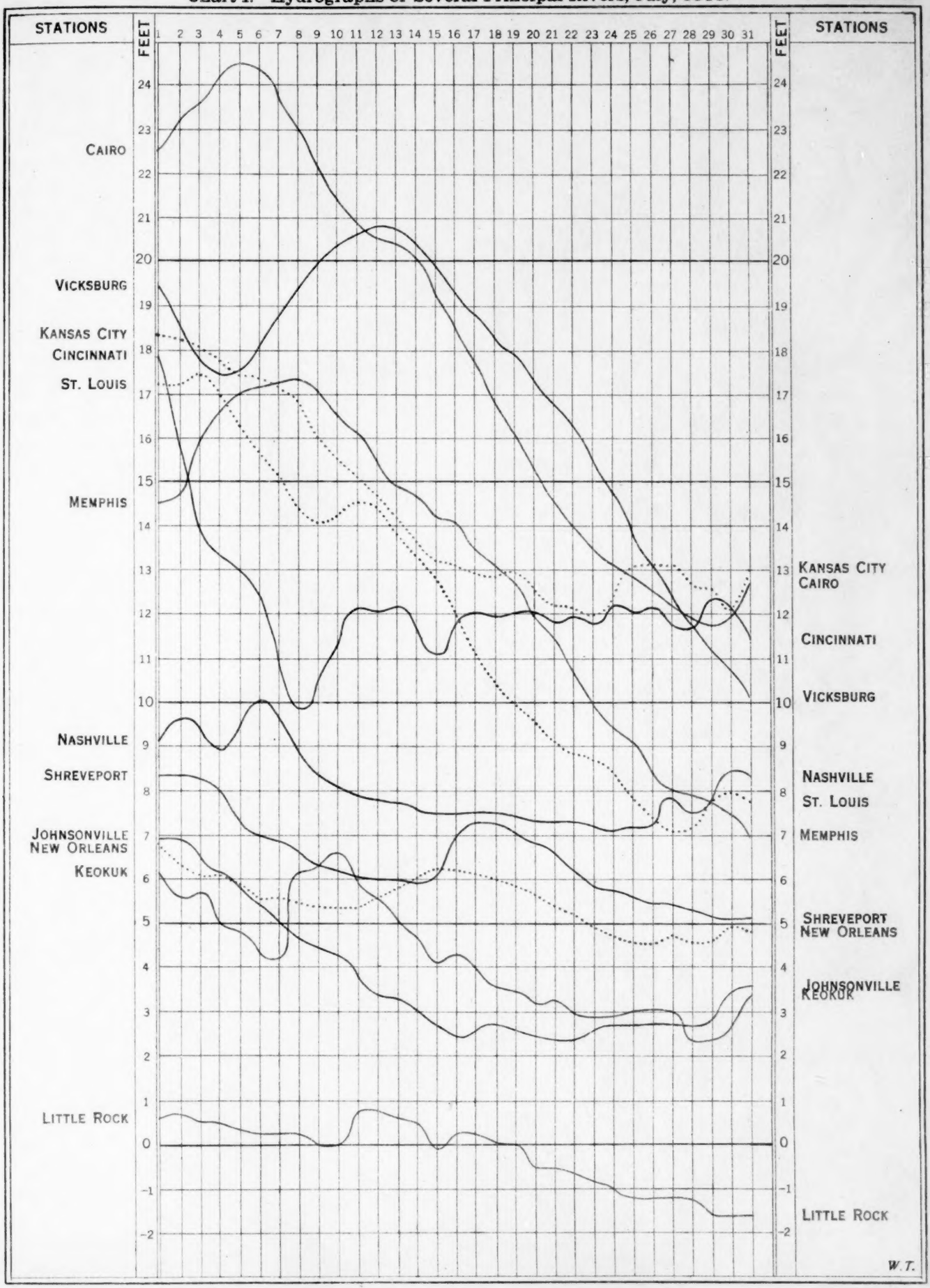


Chart II. Tracks of Centers of High Areas, July, 1918.

(Plotted by Charles A. Donnel.)

Chart III. Tracks of Centers of Low Areas, July, 1918.

Chart III. Tracks of Centers of Low Areas, July, 1918.

(Plotted by Charles A. Donnel.)

Chart IV. Departure (°F.) of the Mean Temperature from the Normal, July, 1918.

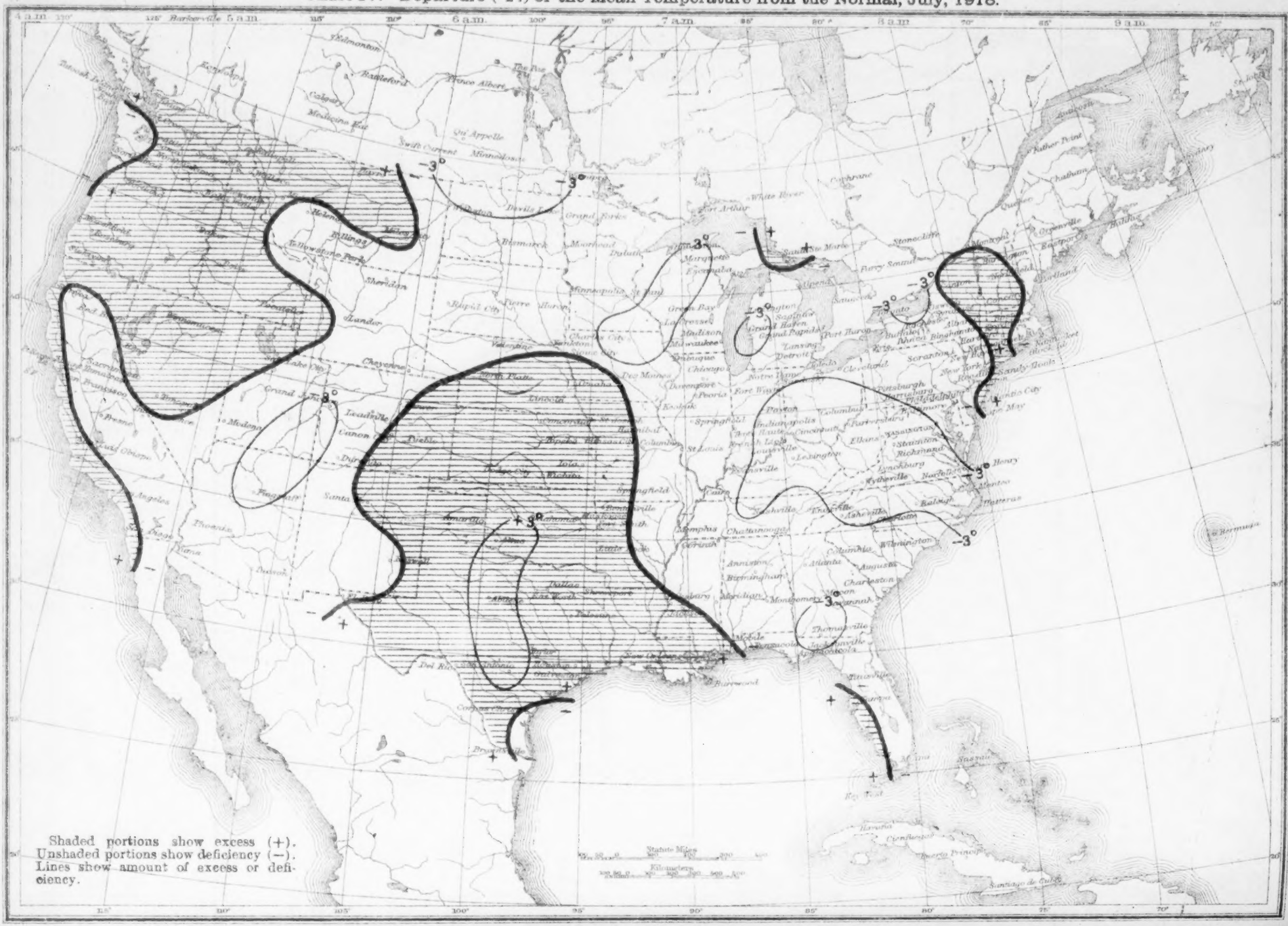

Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.
Statute Miles
Kilometers

Chart V. Total Precipitation, Inches, July, 1918.

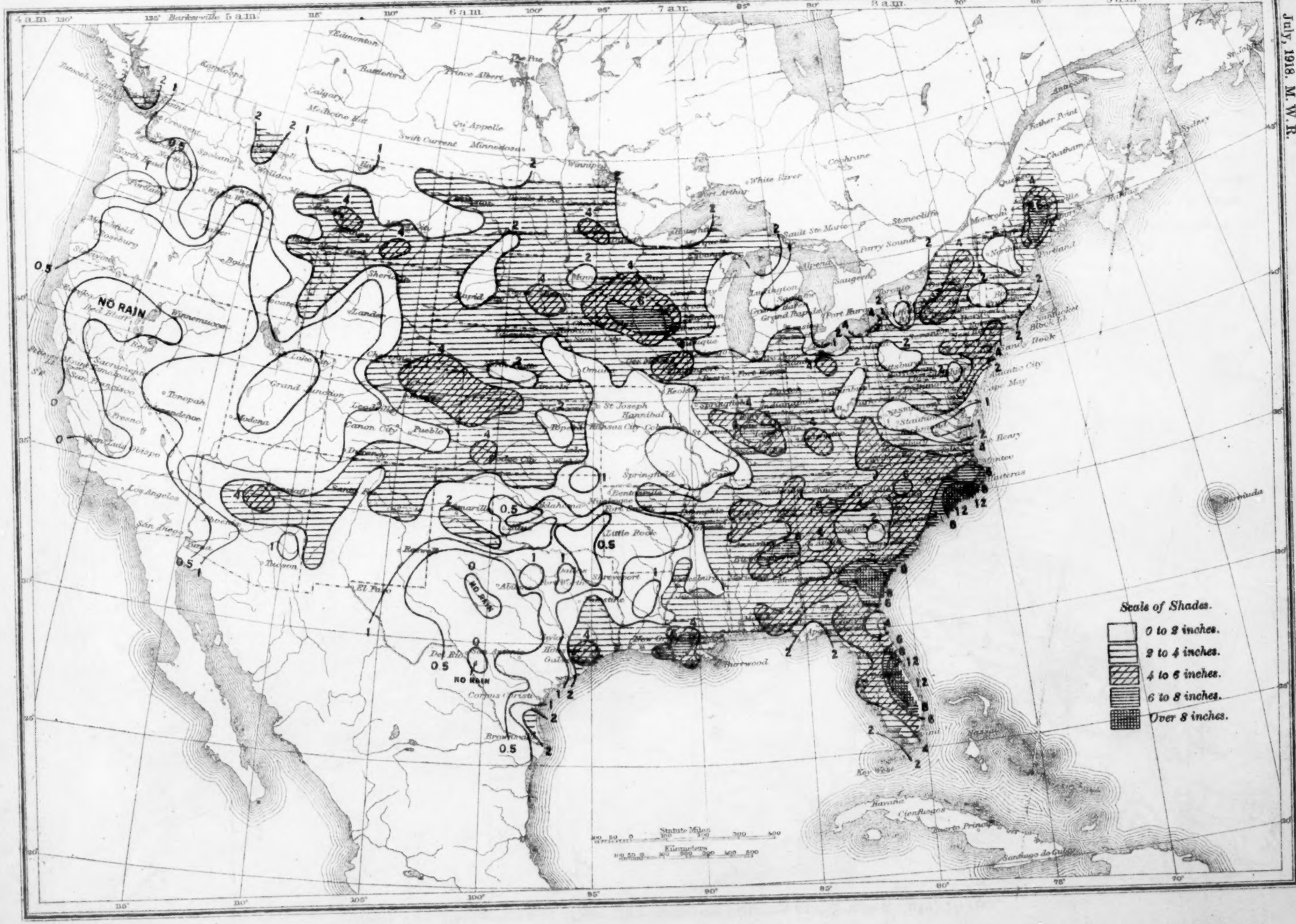


Chart VI. Percentage of Clear Sky between Sunrise and Sunset, July, 1918.

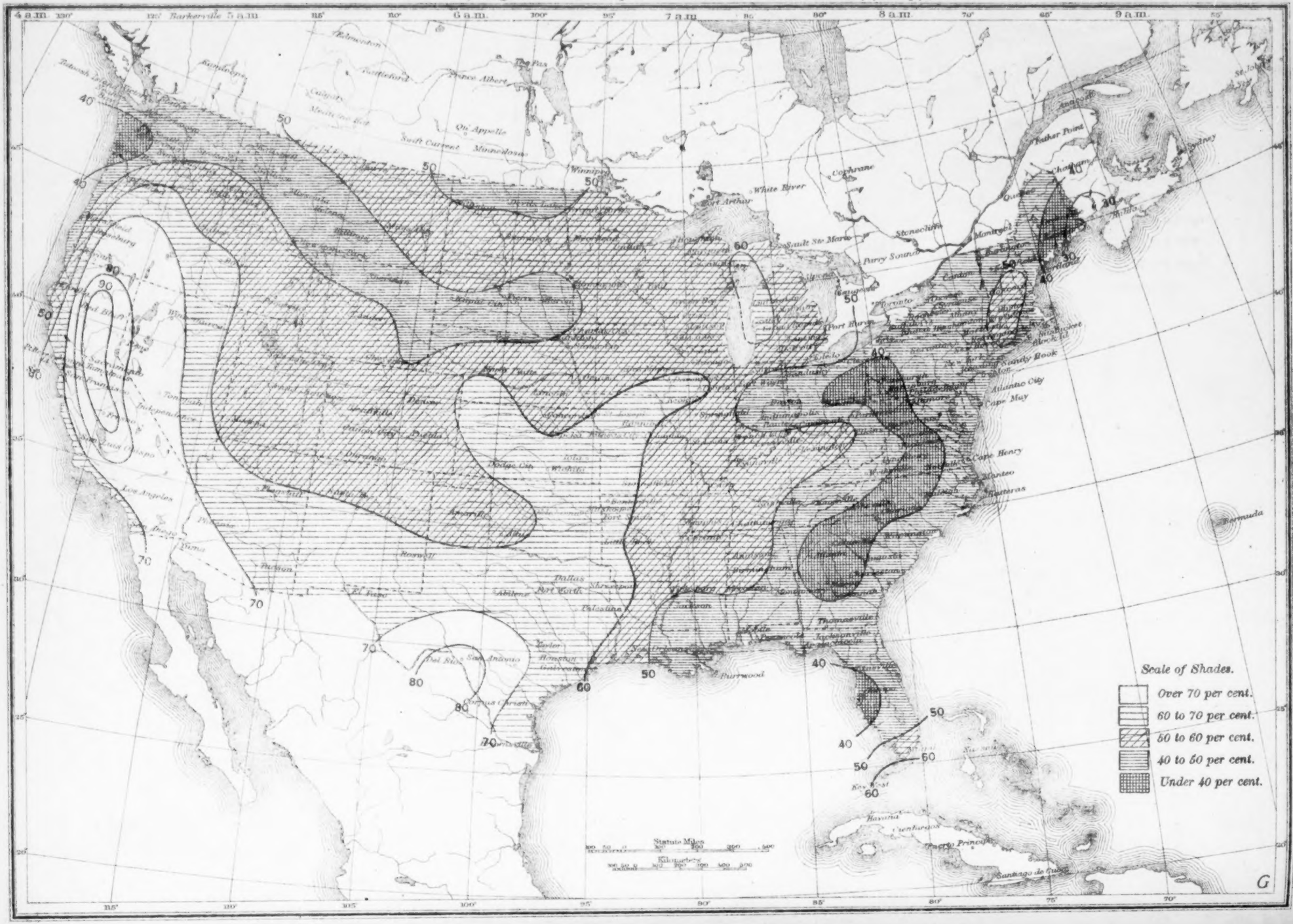


Chart VII. Isobars and Isotherms at Sealevel; Prevailing Winds, July, 1918.

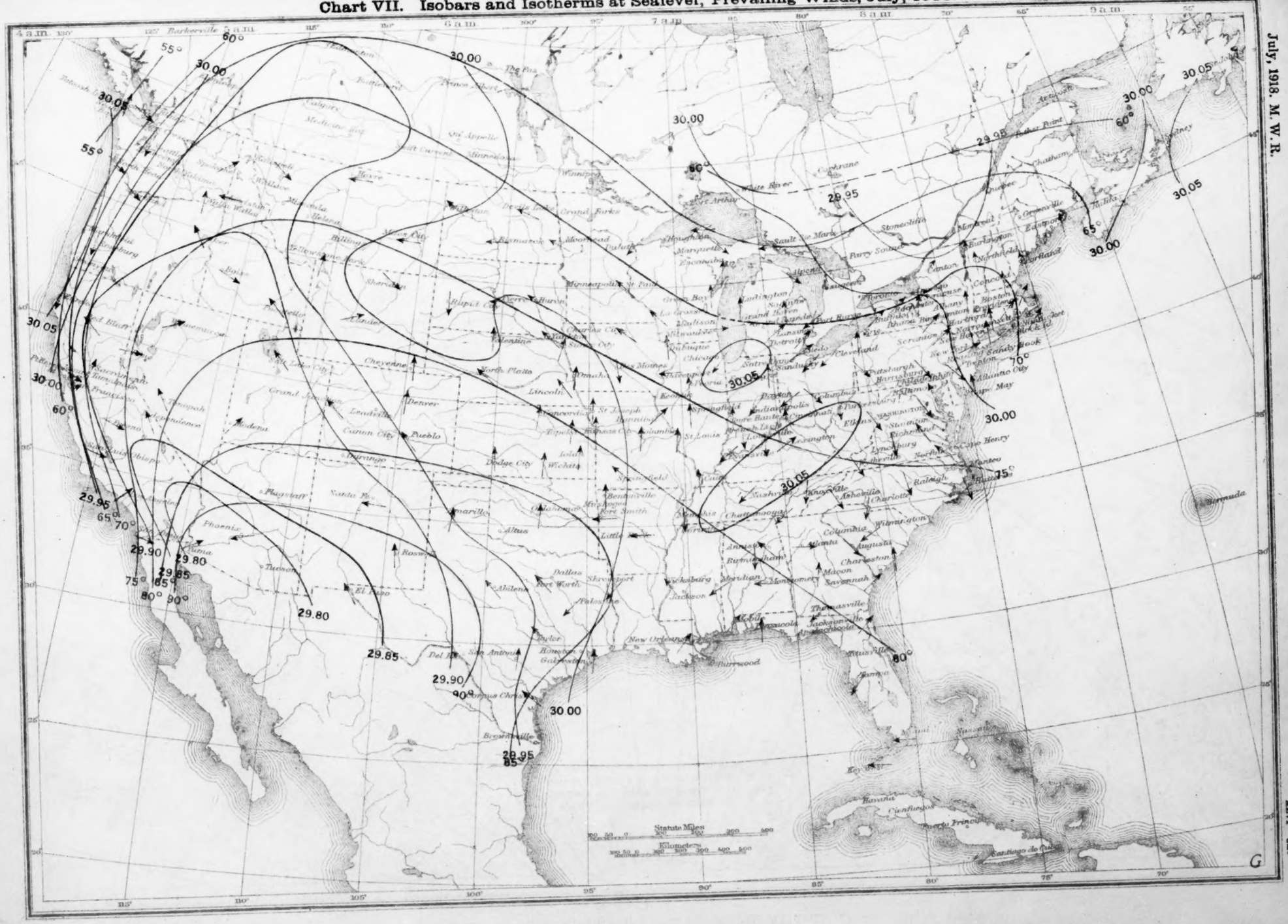
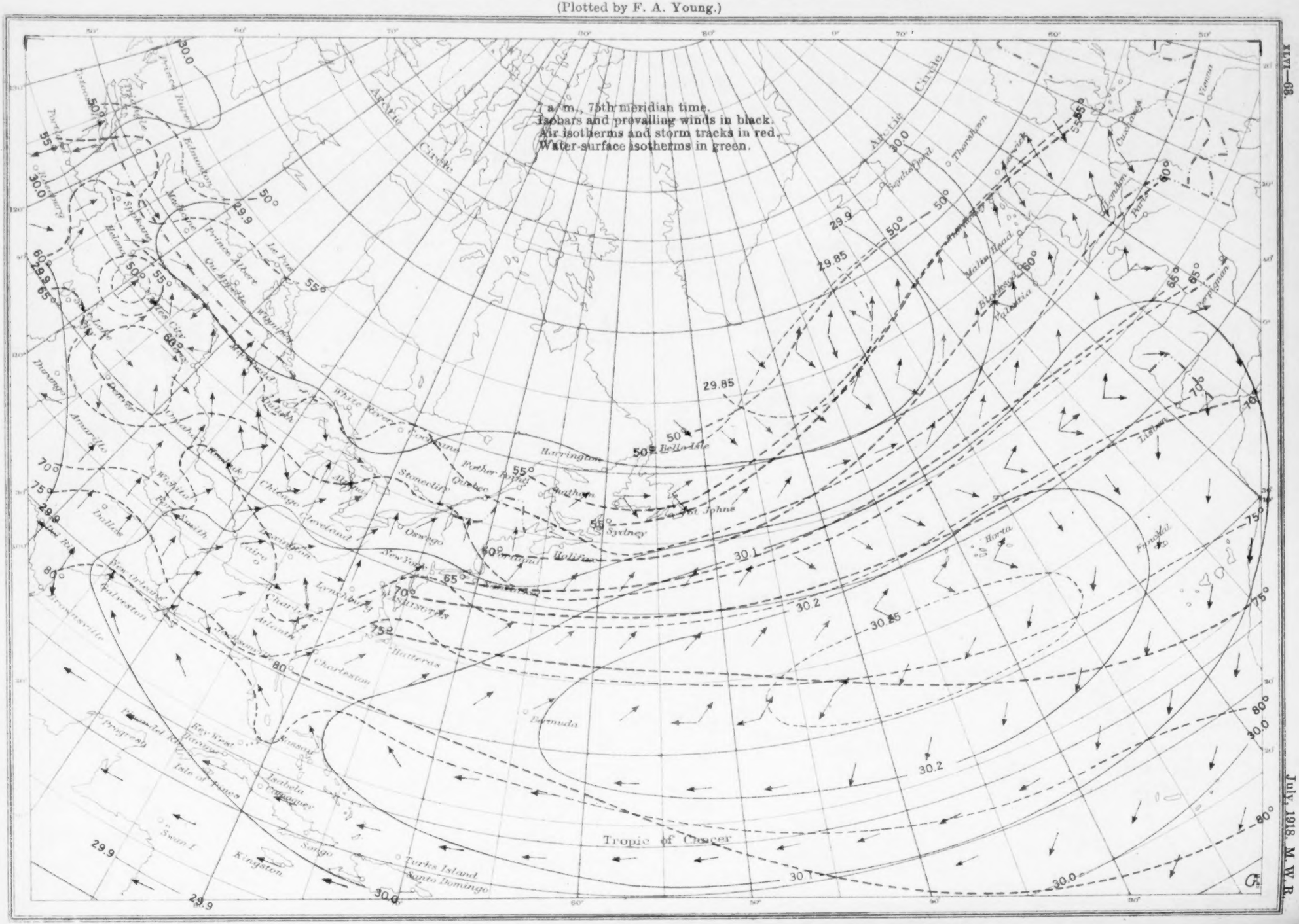

4 a.m.
7 a.m.
6 a.m.
7 a.m.
8 a.m.
9 a.m.
Barkerville
30.00
30.05
29.95
29.90
29.85
29.80
55°
60°
65°
70°
75°
80°
90°
Statute Miles
Kilometers
Bermuda
Havana
Cienfuegos
Nassau
Key West
Tampa
Galveston
New Orleans
Mobile
Jacksonville
Charleston
Savannah
Norfolk
Cape Henry
Atlantic City
Cape May
Sandy Hook
Boston
Portland
Sydney
Quebec
Montreal
Toronto
Chicago
Cleveland
Detroit
Buffalo
Pittsburgh
Denver
Pueblo
Cheyenne
Omaha
Kansas City
St. Louis
Minneapolis
St. Paul
Winnipeg
Duluth
Milwaukee
Salt Lake City
Phoenix
Tucson
El Paso
Dallas
Fort Worth
Houston
San Antonio
Brownsville
Corpus Christi
Vicksburg
Memphis
Atlanta
Birmingham
Montgomery
Jacksonville
Tallahassee
Raleigh
Richmond
Washington
Baltimore
Philadelphia
New York
Albany
Buffalo
Cleveland
Detroit
Chicago
Milwaukee
Minneapolis
St. Paul
Duluth
Winnipeg
Regina
Calgary
Edmonton
Prince Albert
Battleford
Moose Jaw
Medicine Hat
Swift Current
Qu'Appelle
Prince Albert
The Pas
Port Arthur
Fort William
Sault Ste. Marie
Parry Sound
Toronto
Ottawa
Montreal
Quebec
Father Point
Chatham
Moncton
Yarmouth
Halifax
Sydney
Charlottetown
St. John
Eastport
Portland
Boston
Nantucket
Block Island
Sandy Hook
Atlantic City
Cape May
Cape Henry
Norfolk
Wilmington
Columbia
Augusta
Charleston
Savannah
Jacksonville
Tallahassee
Mobile
Pensacola
Key West
Tampa
Havana
Cienfuegos
Nassau
Bermuda
Galveston
New Orleans
Vicksburg
Jackson
Meridian
Montgomery
Birmingham
Memphis
Nashville
Chattanooga
Knoxville
Asheville
Charlotte
Raleigh
Richmond
Washington
Baltimore
Philadelphia
New York
Albany
Buffalo
Cleveland
Detroit
Chicago
Milwaukee
Minneapolis
St. Paul
Duluth
Winnipeg
Regina
Calgary
Edmonton
Prince Albert
Battleford
Moose Jaw
Medicine Hat
Swift Current
Qu'Appelle

Chart IX. Means of Meteorological Data for North Atlantic Ocean, July, 1917.

(Plotted by F. A. Young.)